11 GUGUAN

11.1 Introduction

The island of Guguan is located at 17°19′ N, 145°50′ E in the middle of the Mariana Arc, 32 km south of Alamagan and 67 km north of Sarigan. The third-smallest island in the Mariana Archipelago, Guguan is ~ 3 km long by 2 km wide with a land area of 4.24 km^2 (Fig. 11.1a). This island is formed from 2 volcanoes: a younger volcano in the north and an older, eroded volcano in the south that forms a high plain. The highest point on this island, with an elevation of 287 m, is on the rim of the eroded southern volcano (Fig. 11.1b).

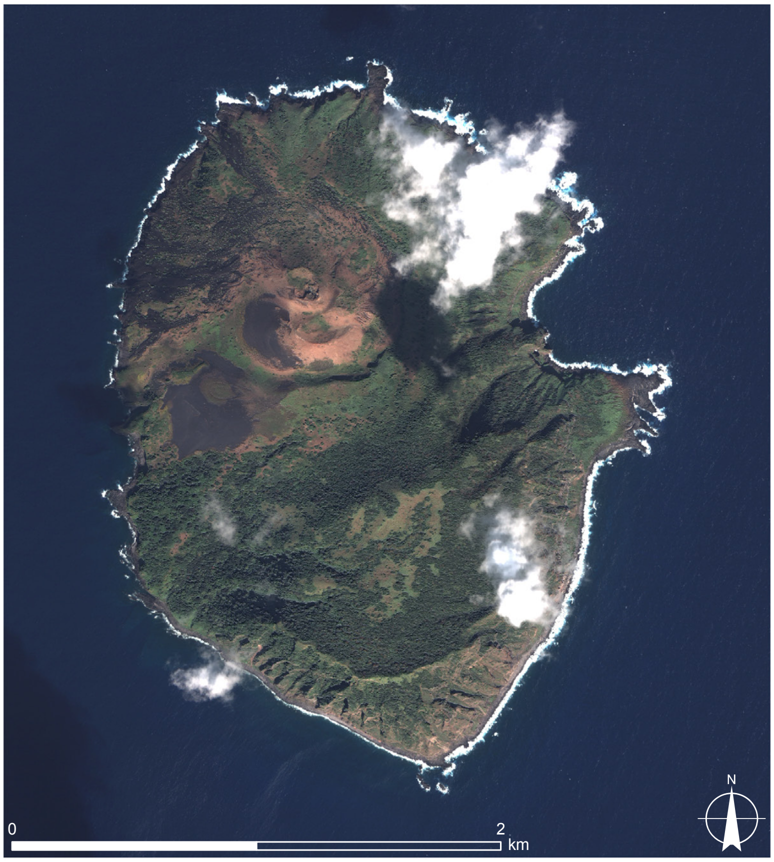


Figure 11.1a. Satellite image of Guguan (© 2004 DigitalGlobe Inc. All rights reserved).

Figure 11.1b. Guguan's eroded south volcano with the only steep slopes on the island, as seen from the NOAA Ship *Hi'ialakai* in 2007. *NOAA photo*

11.1.1 History and Demographics

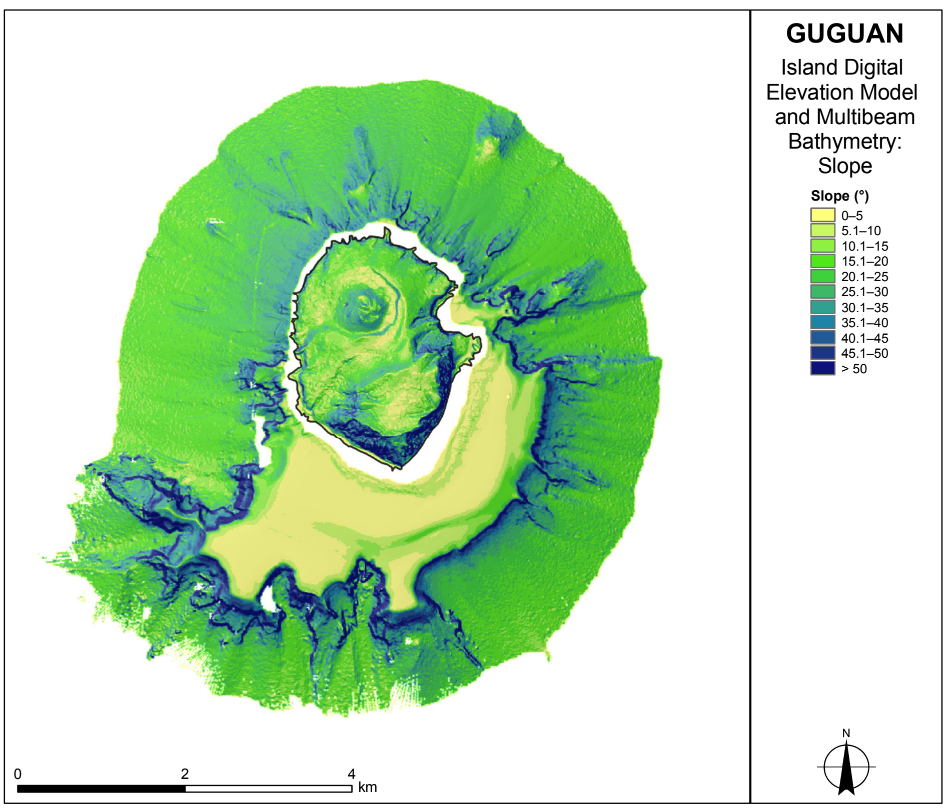
Guguan is not currently and may have never been inhabited. No archaeological evidence of Chamorro occupation has been found (Spennemann 2006), and any inhabitants present on this island in 1695 would have been removed when the Spanish forced inhabitants of the Northern Mariana Islands to relocate to Guam (Rogers 1995). In 1909, while under German administration, Guguan was leased to the Pagan Gesellschaft (a trading association) for exploitation of bird plumage for a period of 3 years, along with Farallon de Pajaros, Maug, Asuncion, Agrihan, Sarigan, and Farallon de Medinilla. During this time, Japanese bird catchers employed on these islands may have been temporary residents (Spennemann 1999b), and other fishing or hunting parties may have resided periodically on this island. Since 1978, the CNMI Constitution has prohibited inhabitation of Guguan (CNMI Constitution).

Guguan falls within the Northern Islands Municipality of the Commonwealth of the Northern Mariana Islands (CNMI), and the political history of Guguan follows that of the CNMI as a whole, which is described in more detail in Chapter 1: "Introduction" and Chapter 8: "Saipan," Section 8.1.1: "History and Demographics."

11.1.2 Geography

In comparison to its neighbor islands, Alamagan and Sarigan, Guguan has a relatively low elevation and less steep slopes. The eroded volcano on the southern part of this island forms a plateau, bounded along the southern coast by the steepest slopes observed on this island (Fig. 11.1.2a). The northern volcano has 3 coalescing cones and a breached summit crater that fed lava flows to the west that resulted from a volcanic eruption in ~ 1883 (Siebert and Simkin 2002). Large cinder fields and cinder cones are also present (Cruz et al. 2000). No eruptions have been recorded since 1883; however, this island is still geologically active, as features of the landscape, such as lagoons formed by craters, seen by visitors to this island in the late 19th and early 20th century are no longer evident possibly as a result of movement of these topographic features (Cruz et al. 2000; Siebert and Simkin 2002).

Figure 11.1.2a. Combined slope map using the digital elevation model and bathymetric data for Guguan (grid cell size: 10 m).



While the lava flows on the northwestern side of this island are not vegetated, the rest of this island supports various types of plant communities (Fig. 11.1.2b). In particular, the southern part of Guguan is heavily vegetated. The southern plateau is dominated by sword grass (*Miscanthus floridulus*), while the rugged hills and valleys support dense forests. Small numbers of coconut palms also are present, likely remaining from previous efforts to establish plantations (Cruz et al. 2000).

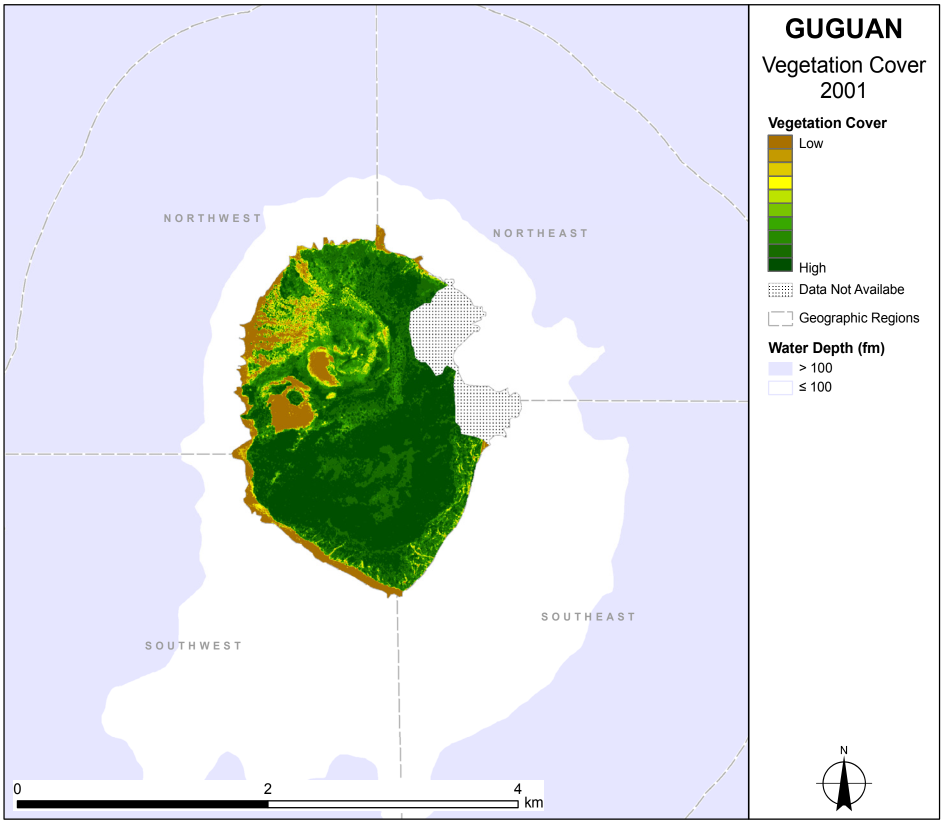


Figure 11.1.2b. Vegetation cover on Guguan, derived using the Normalized Difference Vegetation Index from a satellite image (grid cell size: 4 m; IKONOS Carterra Geo Data, 2001). Hatched lines indicate areas where data are not available because cloud cover obscures the satellite image.

11.1.3 Environmental Issues on Guguan

Guguan is unique, in that it is relatively undisturbed and supports a diverse range of habitats with large numbers of a variety of wildlife species including seabirds, land birds, fruit bats, and coconut crabs. The forests of Guguan support a high abundance and density of native tree species, relative to the forests on other islands of the Mariana Archipelago (Cruz et al. 2000).

Guguan is part of a protected reserve established under Article XIV of the CNMI Constitution and managed by the CNMI Division of Fish and Wildlife. This legislation states that Guguan is to remain uninhabited, and no permanent structures can be built on this island, except for those built to enhance the preservation and protection of natural resources (CNMI Constitution). Guguan is preserved as a habitat for plants and wildlife, including a number of birds species such as the Micronesian starling (*Aplonis opaca*) and Micronesian honeyeater (*Myzomela rubrata*). Guguan, among the northern islands of the Mariana Archipelago, has the highest abundance of the Micronesian megapode (*Megapodius laperouse*), which is listed Federally as endangered and locally as threatened or endangered (U.S. Fish and Wildlife Service; Berger et al. 2005), and has some of the most important seabird rookeries in the northern islands (Cruz et al. 2000). The large bird populations present on Guguan, compared to other islands in the Mariana Archipelago, flourish in the absence of monitor lizards, feral animals, or other large predators, although rats are fairly abundant on some parts of this island (Cruz et al. 2000). Guguan also supports a stable population of the Mariana fruit bat (*Pteropus mariannus mariannus*), an endemic subspecies Federally listed as threatened and locally as threatened or endangered (Cruz et al. 2000; U.S. Fish and Wildlife Service; Berger et al. 2005).

Because of Guguan's isolated location, lack of inhabitants and most feral animals, and its protected status, anthropogenic effects are likely few around this island.

GUGUAN

11.2 Survey Effort

Biological, physical, and chemical observations collected under the Mariana Archipelago Reef Assessment and Monitoring Program (MARAMP) have documented the conditions and processes influencing the coral reef ecosystems around the island of Guguan since 2003. The spatial extent and time frame of these survey efforts are discussed in this section. The disparate areas around this island often are exposed to different environmental conditions. To aid discussions of spatial patterns of ecological and oceanographic observations that appear throughout this chapter, 4 geographic regions around Guguan are delineated in Figure 11.2a; wave exposure and breaks in survey locations were considered when defining these geographic regions. This figure also displays the locations of the Rapid Ecological Assessment (REA) surveys, towed-diver surveys, and towed optical assessment device (TOAD) surveys conducted around Guguan. Potential reef habitat is represented by a 100-fm contour shown in white on this map.

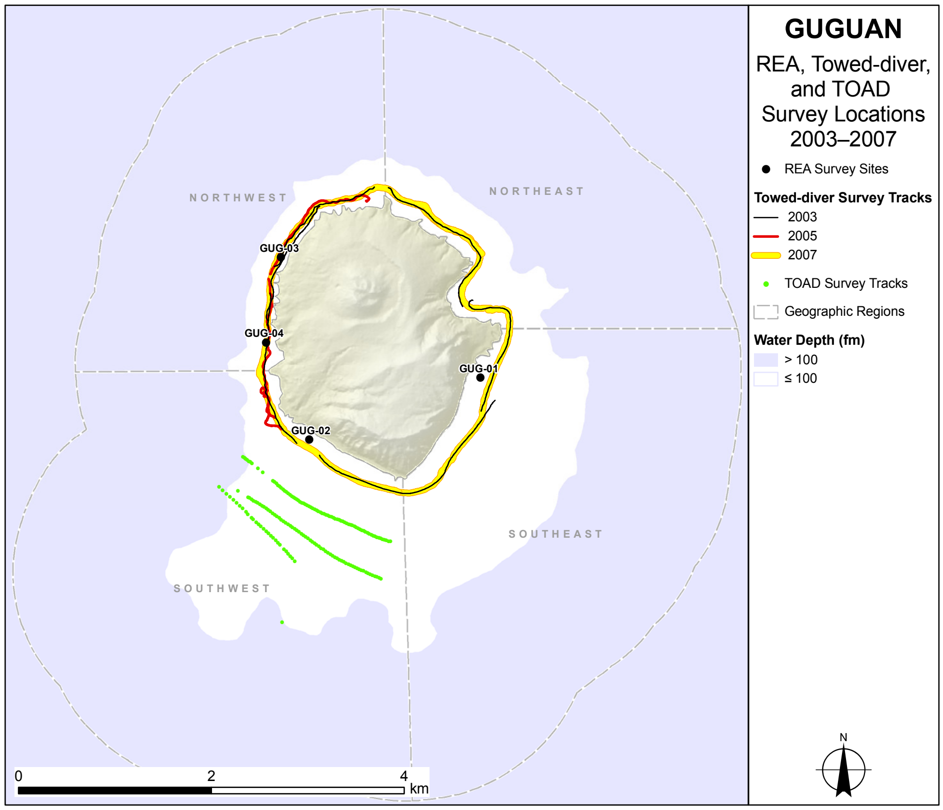


Figure 11.2a. Locations of REA, towed-diver, and TOAD benthic surveys conducted around Guguan during MARAMP 2003, 2005, and 2007. To aid discussion of spatial patterns, this map delineates 4 geographic regions: northeast, southeast, southwest, and northwest.

Benthic habitat mapping data were collected around Guguan using a combination of acoustic and optical-survey methods. MARAMP benthic habitat mapping surveys conducted around this island with multibeam sonar covered a total area of 2228 km^2 in 2007. Optical validation and habitat characterization were conducted using towed-diver and TOAD surveys that documented live-hard-coral cover, sand cover, and habitat complexity. The results of these efforts are discussed in Section 11.3: "Benthic Habitat Mapping and Characterization."

Information on the condition, abundance, diversity, and distribution of biological communities around Guguan was collected using REA, towed-diver, and TOAD surveys. The results of these surveys are reported in Sections 11.5–11.8: "Corals and Coral Disease," "Algae and Algal Disease," "Benthic Macroinvertebrates," and "Reef Fishes." The numbers of surveys conducted during MARAMP 2003, 2005, and 2007 are presented in Table 11.2a, along with their mean depths and total areas and length.

Table 11.2a. Numbers, mean depths (m), total areas (ha), and total length (km) of REA, towed-diver, and TOAD surveys conducted around Guguan during MARAMP 2003, 2005, and 2007. REA survey information is provided for both fish and benthic surveys, the latter of which includes surveys of corals, algae, and macroinvertebrates.

Survey Type	Survey Detail	Year		
REA		**2003**	**2005**	**2007**
Fish	Number of Surveys	3	2	3
	Mean Depth (m)	12 (SD 1)	10 (SD 1.4)	12 (SD 1)
Benthic	Number of Surveys	3	2	3
	Mean Depth (m)	12 (SD 1)	10 (SD 1.4)	12 (SD 1)
Towed Diver		**2003**	**2005**	**2007**
	Number of Surveys	6	3	5
	Total Survey Area (ha)	10.3	3.9	10.5
	Mean Depth (m)	13.7 (SD 1.9)	17.3 (SD 2.9)	16.1 (SD 2.2)
TOAD		**2003**		
	Number of Surveys	3		
	Total Length (km)	6.94		

Spatial and temporal observations of key oceanographic and water-quality parameters influencing reef conditions around Guguan were collected using: (1) subsurface temperature recorders (STR) designed for long-term observations of high-frequency variability of temperature, (2) closely spaced conductivity, temperature, and depth (CTD) profiles of the vertical structure of water properties, and (3) discrete water samples for nutrient and chlorophyll-*a* analyses. CTD casts were conducted during MARAMP 2003, 2005, and 2007, and water samples were collected in 2007 (see Chapter 2: "Methods and Operational Background," Section 2.3: "Oceanography and Water Quality"). A summary of deployed instruments and collection activities is provided in Table 11.2b. Results are discussed in Section: 11.4: "Oceanography and Water Quality."

Table 11.2b. Numbers of STRs deployed, shallow-water and deepwater CTD casts performed, and water samples collected around Guguan during MARAMP 2003, 2005, and 2007. Shallow-water CTD casts and water samples were conducted from the surface to a 30-m depth, and deepwater casts were conducted to a 500-m depth. Deepwater CTD cast information is presented in Chapter 3: "Archipelagic Comparisons".

Observation Type	Year						
Instruments	**2003**	**2005**		**2007**		**2009**	**Lost**
	Deployed	**Retrieved**	**Deployed**	**Retrieved**	**Deployed**	**Retrieved**	
STR	1	1	1	1	1	1	–
CTD Casts	**2003**	**2005**		**2007**			**Total**
Shallow-water Casts	10	6		9			25
Deepwater Casts	–	3		1			4
Water Samples		**2005**		**2007**			**Total**
		–		3			3

Towed-diver Surveys: Depths

Figures 11.2b and c illustrate the locations and depths of towed-diver-survey tracks around Guguan and should be referenced when further examining results of towed-diver surveys from MARAMP 2003, 2005, and 2007.

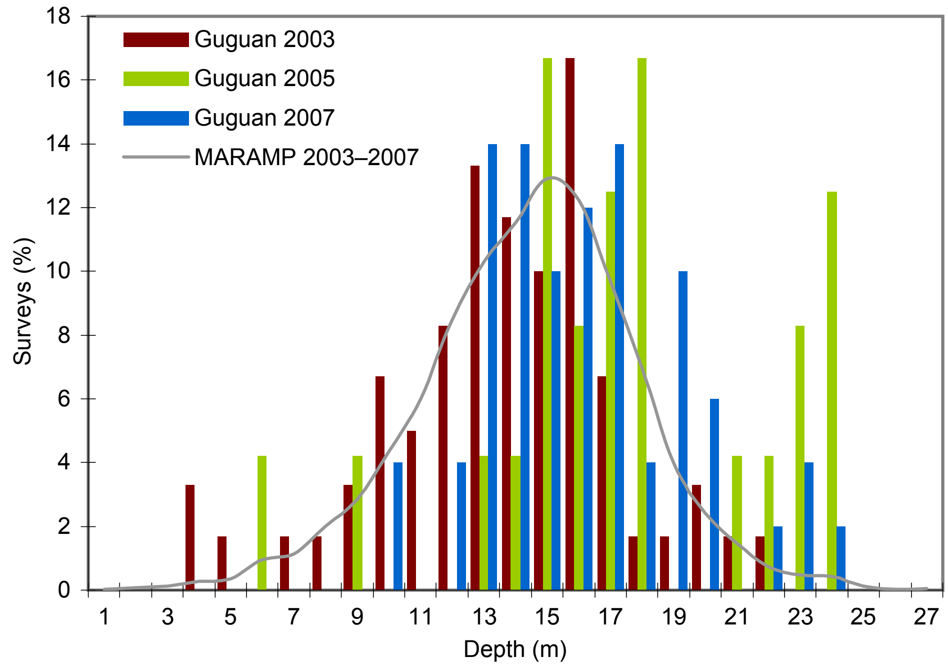


Figure 11.2b. Depth histogram plotted from mean depths of 5-min segments of towed-diver surveys conducted around Guguan during MARAMP 2003. Mean segment depths were derived from 5-s depth recordings. Segments for which no depth was recorded were excluded. The grey line represents average depths from all towed-diver surveys conducted around the Mariana Archipelago during 2003, 2005, and 2007.

During MARAMP 2003, 6 towed-diver surveys were conducted along the forereef slopes around Guguan (Figs. 11.2b and c, top panel). The mean depth of all survey segments was 13.7 m (SD 1.9), and the mean depths of individual surveys ranged from 10.1 m (SD 5.9) to 15.3 m (SD 3).

During MARAMP 2005, 3 towed-diver surveys were conducted along the forereef slopes around part of Guguan (Figs. 11.2b and c, middle panel). The mean depth of all survey segments was 17.3 m (SD 2.9), and the mean depths of individual surveys ranged from 15.3 m (SD 5.5) to 20.6 m (SD 4.4).

During MARAMP 2007, 5 towed-diver surveys were conducted along the forereef slopes around Guguan (Figs. 11.2b and c, bottom panel). The mean depth of all survey segments was 16.1 m (SD 2.2), and the mean depths of individual surveys ranged from 13.7 m (SD 2.9) to 19.2 m (SD 4.2).

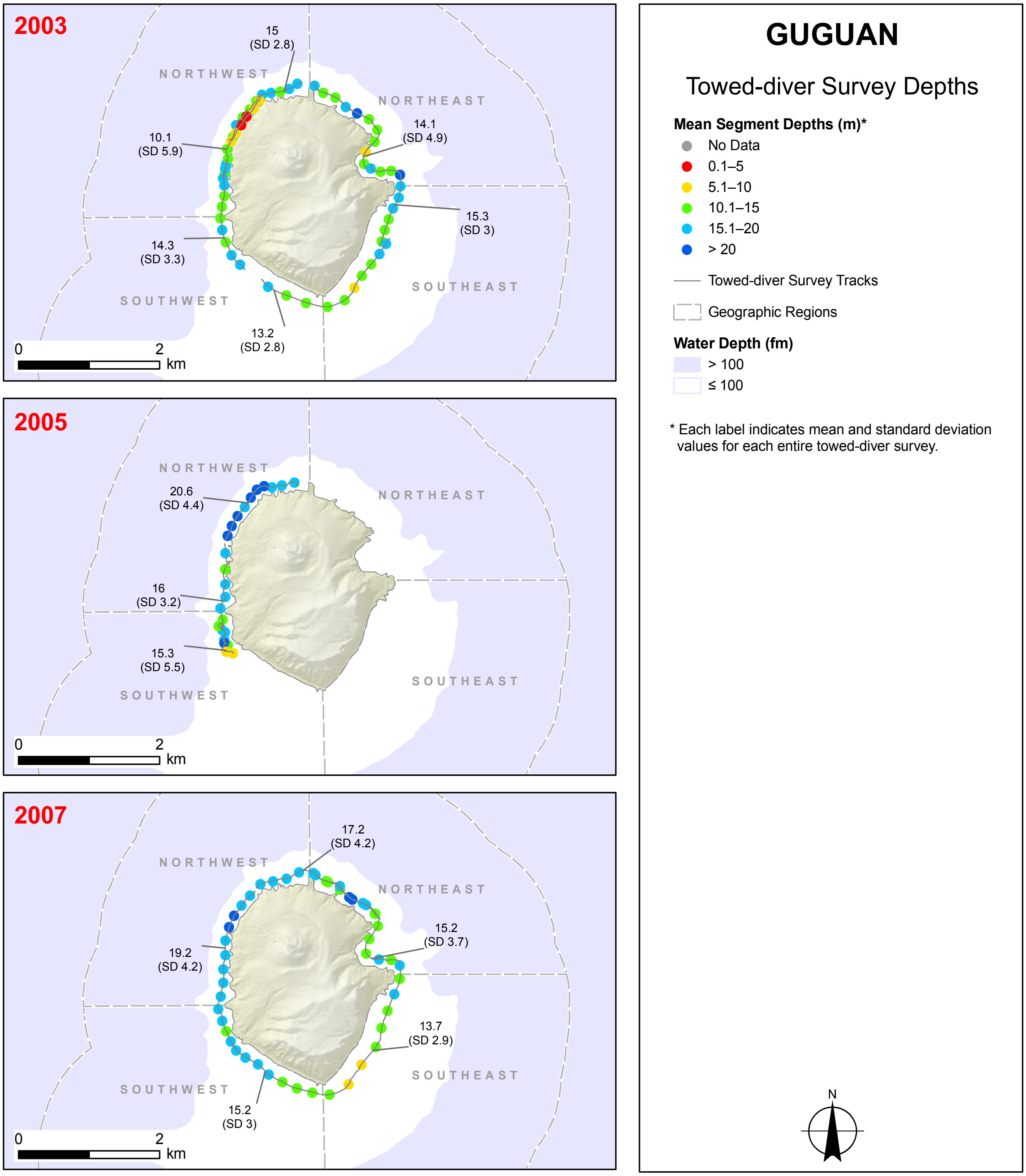


Figure 11.2c. Depths and tracks of towed-diver surveys conducted around Guguan during MARAMP 2003, 2005, 2007. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.

11.3 Benthic Habitat Mapping and Characterization

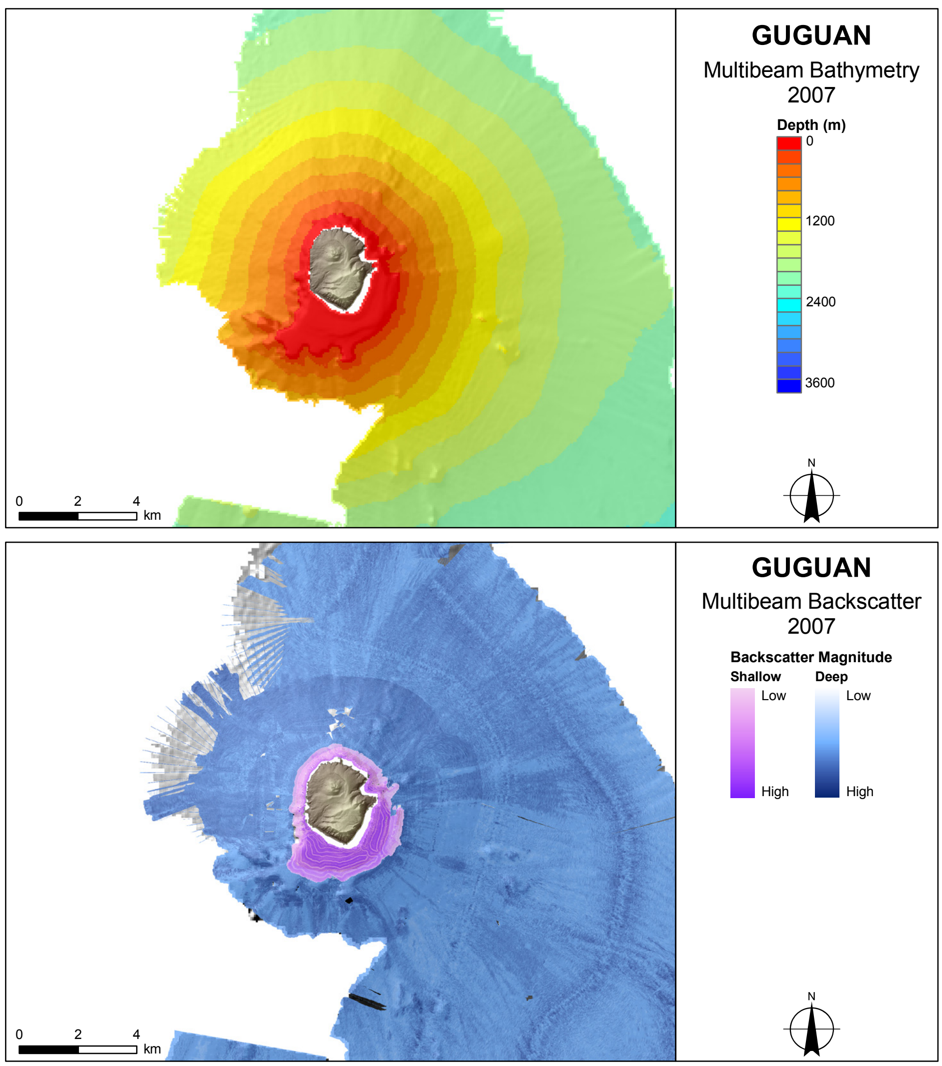
Benthic habitat mapping and characterization surveys around the island of Guguan were conducted during MARAMP 2003, 2005, and 2007 using acoustic multibeam sonar, underwater video and still imagery, and towed-diver observations. Acoustic multibeam sonar mapping provided bathymetric and backscatter data products over the depth range of ~ 15–2300 m. Optical validation and benthic characterization, via diver observations and both video and still underwater imagery, were performed using towed-diver surveys and TOAD deployments conducted at depths of < 270 m.

11.3.1 Acoustic Mapping

Multibeam acoustic bathymetry and backscatter imagery (Fig. 11.3.1a) collected by the Coral Reef Ecosystem Division (CRED) around the islands of Guguan, Alamagan, Zealandia Bank, Sarigan, and Anatahan during MARAMP 2007 encompassed an area of 2228 km^2. Good coverage was achieved east of Guguan, with multibeam data obtained at depths down to 1990–2340 m, but coverage west of Guguan was limited to a maximum depth of 900–1600 m.

The low-resolution multibeam bathymetry data collected around Guguan reveal fairly uniform slopes around much of this island (Fig. 11.3.1a, top panel). The data show the flanks to be smooth, with very little blocky material usually indicative of mass wasting (the movement of soil and surface materials by gravity). South of Guguan, the seabed character is very different, with irregularly shaped shelves. A shallow shelf is located at depths of 25–50 m, and another shelf is present at depths of 80–130 m. Ridges and channels radiate from the edge of this deep shelf.

Figure 11.3.1a. Gridded (*top*) multibeam bathymetry (grid cell size: 60 m) and (*bottom*) backscatter (grid cell size: 5 m) collected around Guguan during MARAMP 2007 in depths of 15–2300 m. Shallow-backscatter data (shown in purple) were collected using a 240-kHz Reson SeaBat 8101 ER sonar, and deep-backscatter data (shown in blue) were collected using a 30-kHz Kongsberg EM 300 sonar. Light shades represent low-intensity backscatter and may indicate acoustically absorbent substrates, such as unconsolidated sediment. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom or coral substrates.



As described in Chapter 2: "Methods and Operational Background," Section 2.2: "Benthic Habitat Mapping and Characterization," multibeam backscatter intensity can provide information about the roughness and hardness of the seafloor. Low-resolution backscatter data collected around Guguan appear to have some artifacts, which make it difficult to determine patterns in the acoustic characteristics of the seabed. These artifacts are most noticeable north of Guguan, where there is a sharp contrast between shallow and deep swaths, and east of the island, where some linear patterns are shown on the backscatter map (Fig. 11.3.1a, bottom panel) but do not appear to relate to any bathymetric feature. Despite these issues, the backscatter data generally appear to correlate to topographic features. The most obvious patterns are on the shelves south of this island. High-intensity backscatter is recorded on the shallow shelf, suggesting that this shelf likely is composed of hard substrates. In contrast, the deep shelf is characterized by low-intensity backscatter, indicative of soft substrates. Below the deep shelf, the radiating ridges are characterized by high-intensity backscatter, whereas the channels in between have lower backscatter intensity suggesting the accumulation of soft sediments.

High-resolution Multibeam Bathymetry and Derivatives

High-resolution multibeam data collected in nearshore (0–800 m) waters around Guguan were combined into a grid at 10-m resolution to allow for the identification of fine-scaled features (Fig. 11.3.1b). These high-resolution data also were used to derive benthic maps of slope (Fig. 11.3.1c), rugosity (Fig. 11.3.1d), and bathymetric position index (BPI) zones (Fig. 11.3.1e). Together, these maps provide layers of information to characterize the benthic habitats around Guguan.

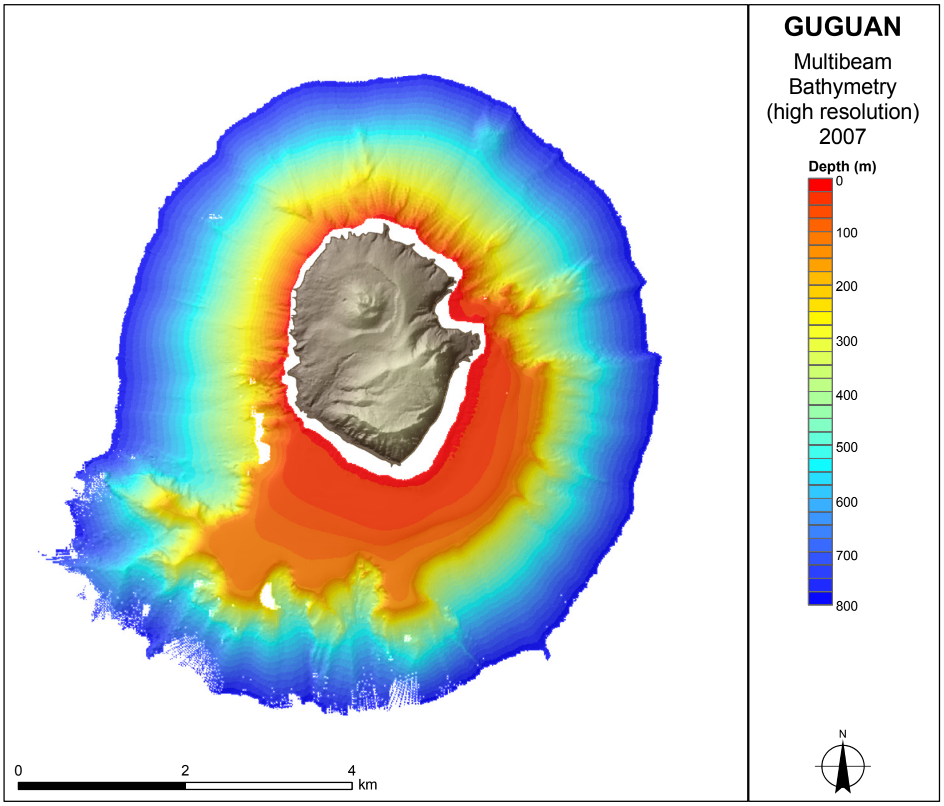


Figure 11.3.1b. High-resolution multibeam bathymetry collected around Guguan during MARAMP 2007. This 10-m bathymetry grid, clipped at 800 m, is used as the basis for slope, rugosity, and BPI derivatives.

Northeast and northwest of Guguan, narrow ridges begin in the shallowest areas surveyed and continue to depths of 100–300 m. Apart from these ridges, the flanks are characterized by relatively smooth, moderately steep (15°–25°) slopes, highlighted by the homogeneity of the BPI zones mapped in these areas (Fig. 11.3.1e). In the northeast region, the seabed within a small bay is characterized by low-rugosity values and no slopes, and the BPI analysis delineates a small flat zone.

The high-resolution multibeam bathymetry data display the detail of the shelves that surround the southern and southeastern coasts of this island. The BPI analysis suggests that these shelves provide a large area of flat seabed in an otherwise steeply sloping terrain. The shallow shelf is shown in the slope map to be flat and smooth. The inner edge of the shallow shelf is bordered by a narrow zone of complex topography that may represent spur-and-groove habitat. A low to moderately steep slope (5°–20°) separates the shallow shelf from the deeper one, which itself gently slopes to the shelf break at 130–140 m. Along the shelf edge, very steep slopes of > 50° are shown in the slope map, from which narrow ridges extend.

Some of these ridges are very short, but others extend for more than 1 km horizontally. Between the ridges, narrow channels are shown. In some locations, the irregular shelf edge forms submarine peninsulas with wide channels between them. The steep sides of these channels are highlighted by the slope and rugosity maps.

Figure 11.3.1c. Slope (°) of 10-m bathymetric grid around Guguan. Derived from data collected in 2007, this map reflects the maximum rate of change in elevation between neighboring cells with the steepest slopes shown in the darkest shades of blue and the flattest areas in yellow shades.

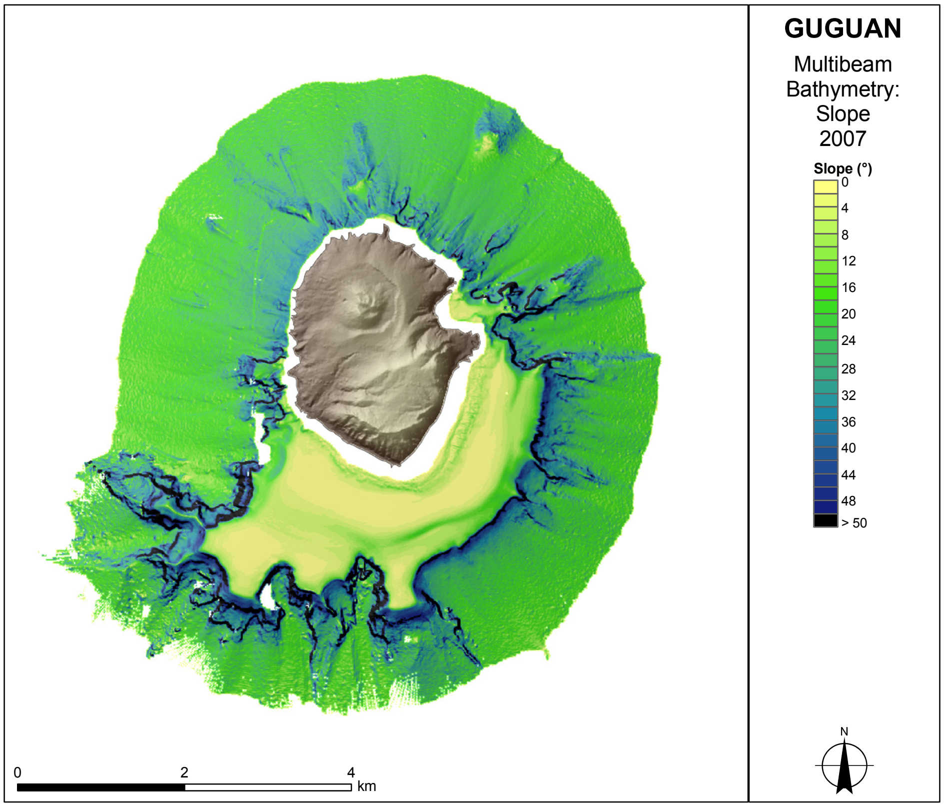
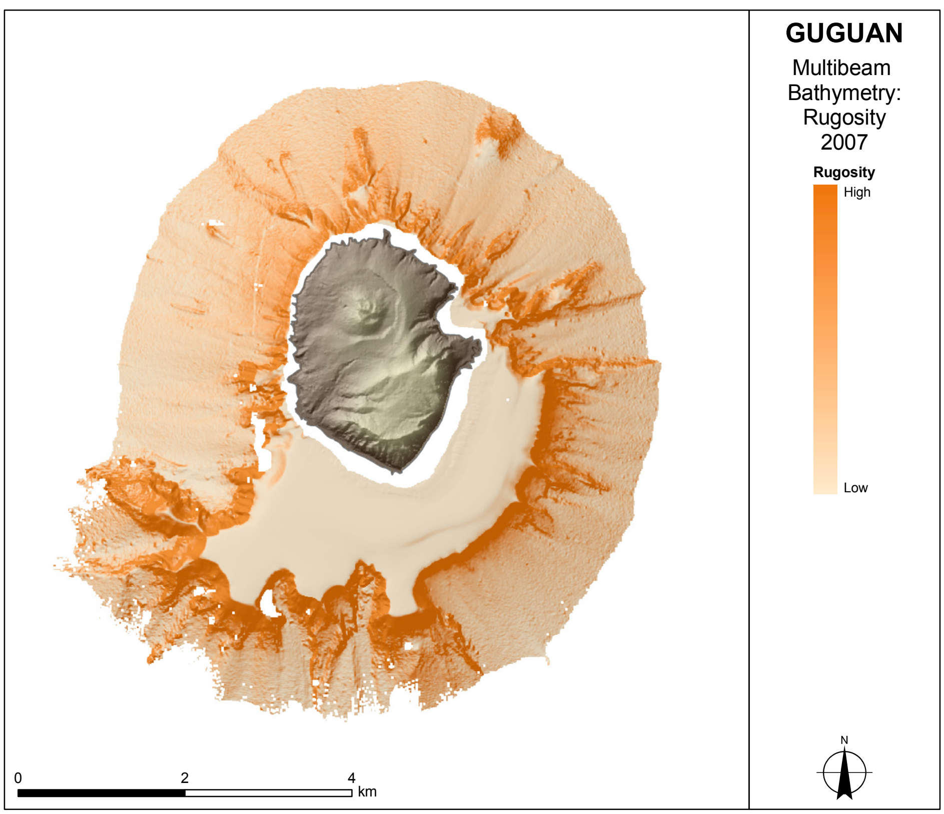


Figure 11.3.1d. Rugosity of 10-m bathymetric grid around Guguan. Derived from data collected in 2007, these rugosity values are a measure of the ratio of surface area to planimetric area within a given cell's neighborhood and indicate topographic roughness.



Reef crests are identified by the BPI analysis in the shallowest waters surveyed around northern Guguan; however, this classification is likely an artifact of the methodology, since no data are available for immediately inshore areas and no comparison can be made to the innermost cells of the grid. Instead, these areas probably should be characterized as slopes.

Overall, the topographic character of Guguan, which is characterized by steep slopes to the north and west and an extensive shelf to the south, appears to be very similar to the topography of neighboring island Sarigan.

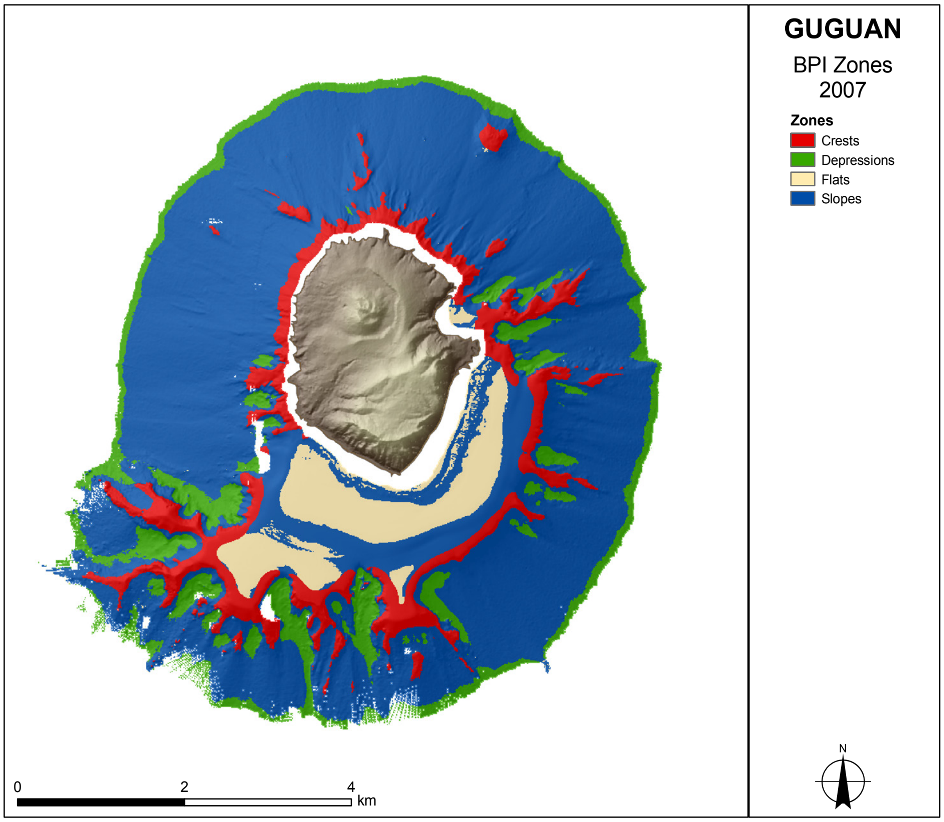


Figure 11.3.1e. BPI zones of 10-m bathymetric grid around Guguan derived from data collected in 2007. BPI is a second-order derivative of bathymetry that evaluates elevation differences between a focal point and the mean elevation of the surrounding cells within a user-defined circle. Four BPI Zones—crests, depressions, flats, and slopes—were used in this analysis.

High-Resolution Multibeam Backscatter and Derivatives

High-resolution backscatter data acquired around Guguan, in particular data collected north of this island, have some noticeable artifacts, such as data gaps and other patterns that may result from steep slopes rather than acoustic properties of the seafloor (Fig. 11 3.1f). Nevertheless, some patterns are evident that appear to relate to seafloor characteristics, and these are most clearly seen in the areas where greatest coverage was achieved. To reduce the effect of these artifacts on the hard–soft classification, the backscatter data were clipped to a depth of 100 m prior to carrying out this classification. Although the hard–soft analysis is a useful tool to help interpret the seabed character around Guguan, it should be noted that the ground-truthing data underlying the classification were based on other islands with different geological characteristics, and no specific ground-truthing data were available from Guguan to inform this classification. Nevertheless, this classification does provide some indication of the distribution of different substrate types around this island.

Data collected on the shelf area south and east of Guguan are characterized by high backscatter values, and the hard–soft analysis classifies these same areas as having hard substrates (Figs. 11 3.1f and g). As the shelf deepens south of Guguan, the backscatter intensities lessen, and the outer shelf area is classified as having soft substrates, although the depth and slope may also influence these data. East of this island, the submerged peninsula extending from the shelf is classified as having hard substrates, with soft substrates recorded in the channels on either side.

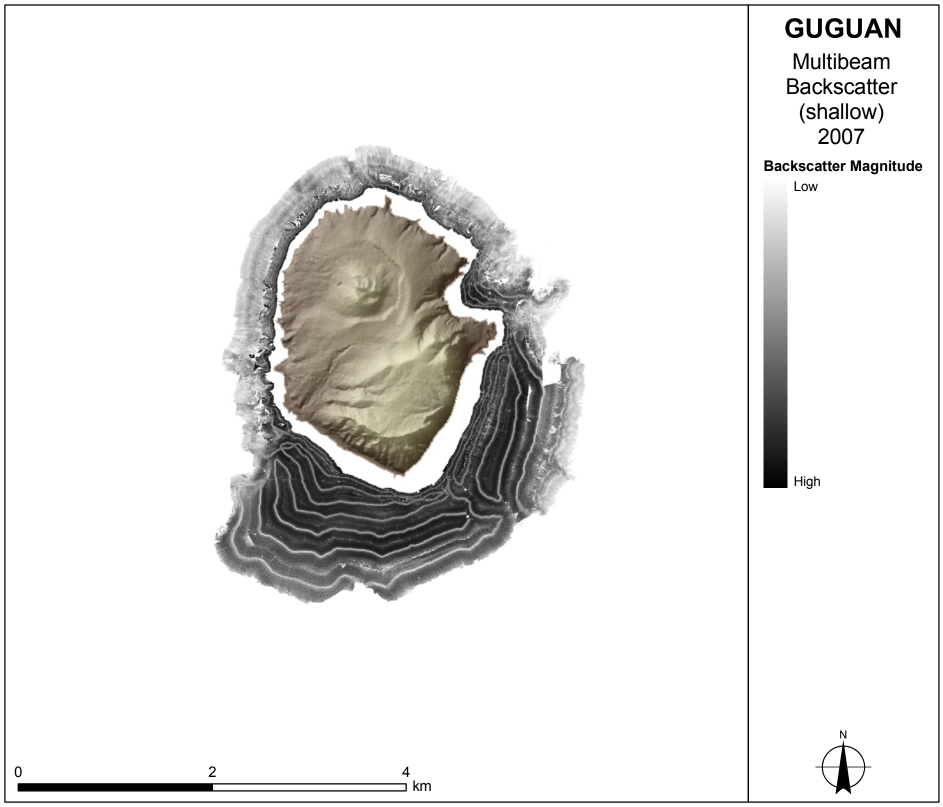


Figure 11.3.1f. Gridded, high-resolution, multibeam backscatter data (grid cell size: 1 m) collected around Guguan during MARAMP 2007. Light shades represent low-intensity backscatter and may indicate acoustically absorbent substrates. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom and coral substrates.

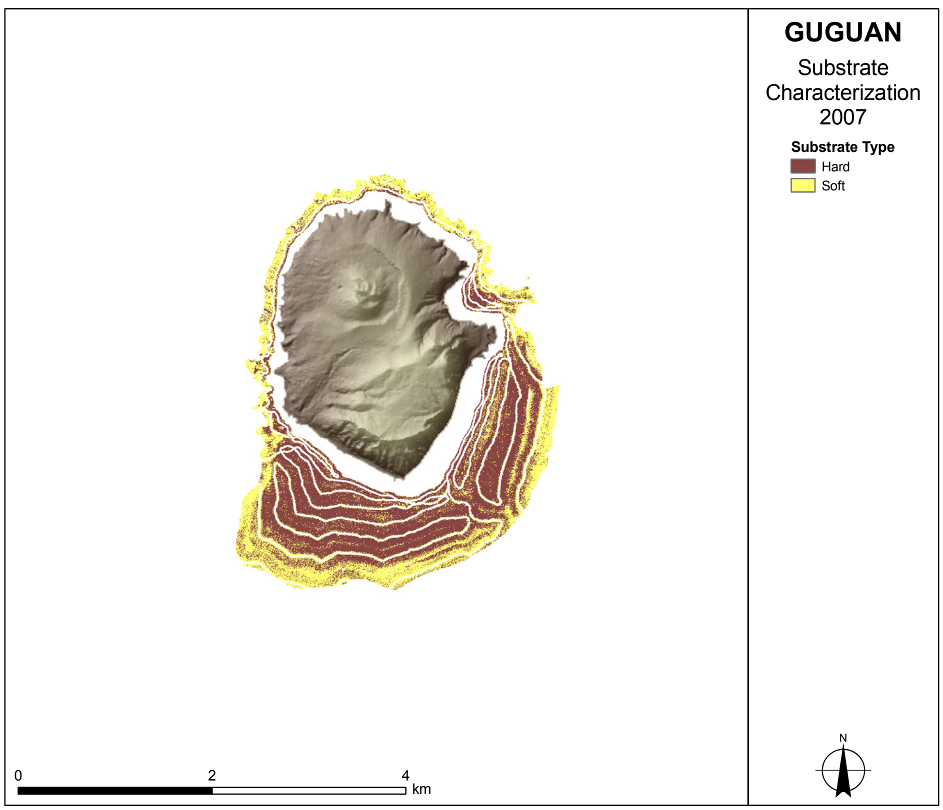


Figure 11.3.1g. Hard and soft substrates (grid cell size: 5 m) at depths < 100 m based upon an unsupervised classification of multibeam bathymetry and backscatter data acquired around Guguan in 2007. Data cannot be collected directly under the ship, hence the white lines showing the ship's path.

11.3.2 Optical Validation

During MARAMP 2003, 3 TOAD optical-validation surveys, covering a distance of ~ 7 km at depths of 41–270 m, were conducted around Guguan (Fig. 11.3.2a). Subsequent analyses of video acquired from these surveys provided estimates of the percentages of sand cover and live-hard-coral cover.

Covering a distance of 25 km at depths of 4–24 m, 14 towed-diver optical-validation surveys were conducted around Guguan during MARAMP 2003, 2005, and 2007. At 5-min intervals within each survey, divers recorded percentages of sand cover and live-hard-coral cover and habitat complexity using a 6-level categorical scale from low to very high.

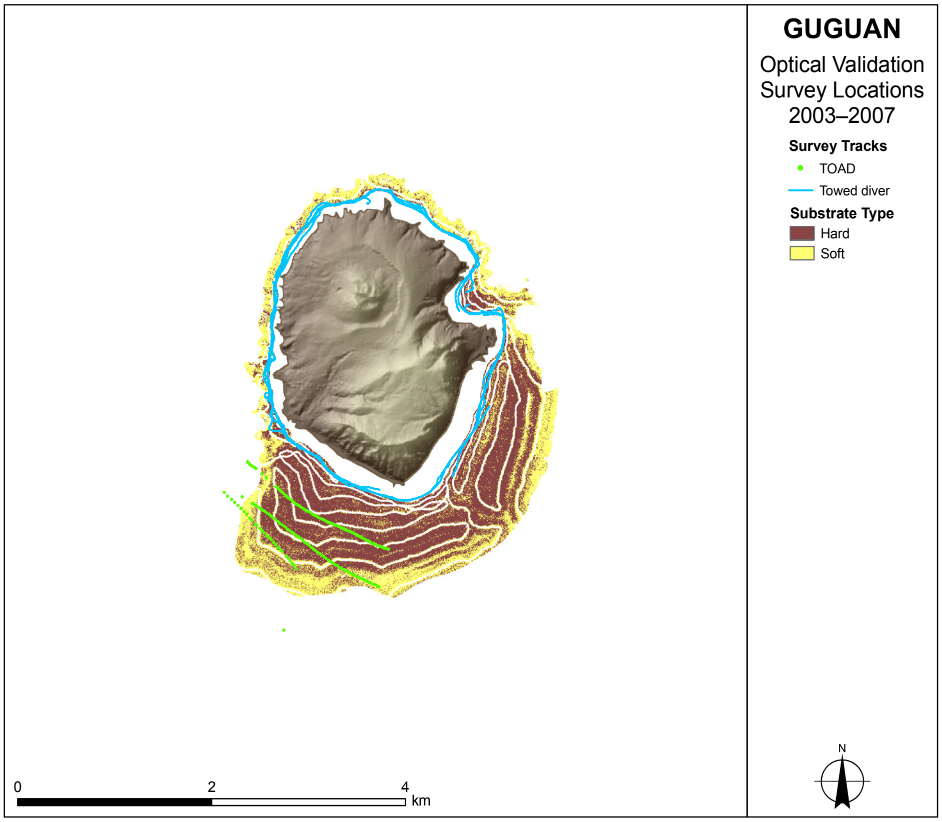


Figure 11.3.2a. Towed-diver tracks from surveys conducted around Guguan during MARAMP 2003, 2005, and 2007 and TOAD camera-sled tracks for MARAMP 2003. Survey tracks are displayed over multibeam hard–soft substrate map. Data cannot be collected directly under the ship, hence the white lines showing the ship's path.

11.3.3 Habitat Characterization

Sand cover, habitat complexity, and live coral cover around Guguan are discussed in this section. These descriptions are organized by the 4 geographic regions around Guguan.

In the northeast and northwest regions, where the seabed is characterized by steep slopes and narrow ridges, the substrate was predominantly hard, as suggested by the low sand cover (< 10%) recorded during towed-diver surveys, relative to other areas surveyed in the Mariana Archipelago (Fig. 11.3.3a, top panel). Habitats of medium to high complexity were characterized as high-relief, spur-and-groove formations with some walls (Fig. 11.3.3a, middle panel). Live coral cover was consistently observed at moderately high levels compared to other islands in the Mariana Archipelago, and interpolated live coral cover in these regions primarily was 10.1%–40% but reached 75% for 2 segments in the northeast region (Fig. 11.3.3a, bottom panel). Around the eastern point of Guguan, in an area of medium to high complexity habitats, interpolated live coral cover of 20.1%–62.5% was recorded.

In the southwest and southeast regions, towed divers surveyed the shallow shelf. There, habitat complexity was lower than the habitats observed north of this island. Habitats along the southern coast of Guguan were classified as medium-low to medium-high complexity in most locations. Sand cover was higher there than on the non-shelf areas with interpolated sand cover of 1.1%–50% recorded. The highest sand cover was observed around the southern point of this island. Live coral cover varied around Guguan, with the lowest levels of coral cover (< 20%) observed around the southern point and in the southwest region, corresponding to the areas of highest sand cover. Analyses of the video footage acquired from TOAD surveys made on the deeper shelf in the southwest region at depths of 41–270 m suggested that the substrate there was also sandy, with 100% sand cover observed in nearly all video frames. This high sand cover contrasts the hard–soft analysis that classified this area as one of hard substrates. This disparity likely is a result of this shelf area's support of a thin veneer of sand, visible on the video footage but not of sufficient depth to influence acoustic characteristics. Low live coral cover was observed in this TOAD video footage, with only 2 video frames from a single survey at depths of 33–34 m suggesting coral cover of 20%. The remainder of analyzed video footage was devoid of visible benthic fauna.

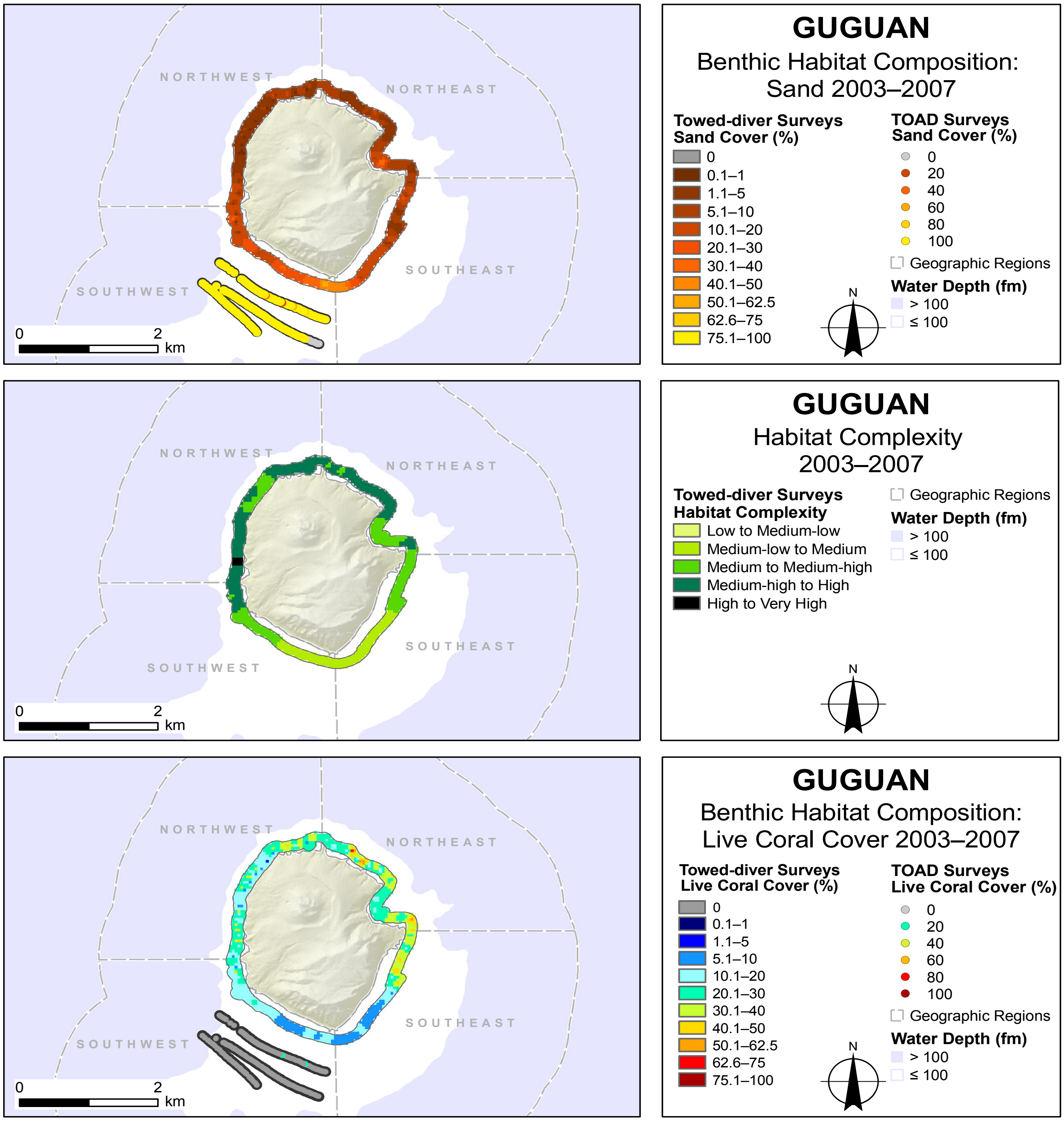


Figure 11.3.3a. Observations of (*top*) sand cover (%), (*middle*) benthic habitat complexity, and (*bottom*) live-hard-coral cover (%) from towed-diver surveys conducted and analyses of TOAD video collected around Guguan during MARAMP 2003, 2005, and 2007.

11.4 Oceanography and Water Quality

11.4.1 Hydrographic Data

2003 Spatial Surveys

During MARAMP 2003, 10 shallow-water conductivity, temperature, and depth (CTD) casts were conducted in nearshore waters around the island of Guguan on September 11. Temperature, salinity, and density values varied both spatially and vertically around this island. Spatial comparisons of water properties at a depth of 10 m suggest small differences in temperature (0.1°C), salinity (0.1 psu), and density (0.1 kg m^{-3}) values; however, recorded temperature values were slightly lower and salinity values were higher in the northwest and northeast regions (casts 1-6) than in the southwest and southeast regions (casts 7–10; Fig. 11.4.1a). Vertical comparisons of CTD profiles reveal water properties with a moderate range in temperature (0.8°C), salinity (0.2 psu), and density (0.5 kg m^{-3}) values (Fig. 11.4.1b). Well-mixed waters were recorded around most of Guguan (casts 4–10), except in the northwest region (casts 1–3), where increased stratification was observed because of the presence of cool, subsurface water at depths > 15 m.

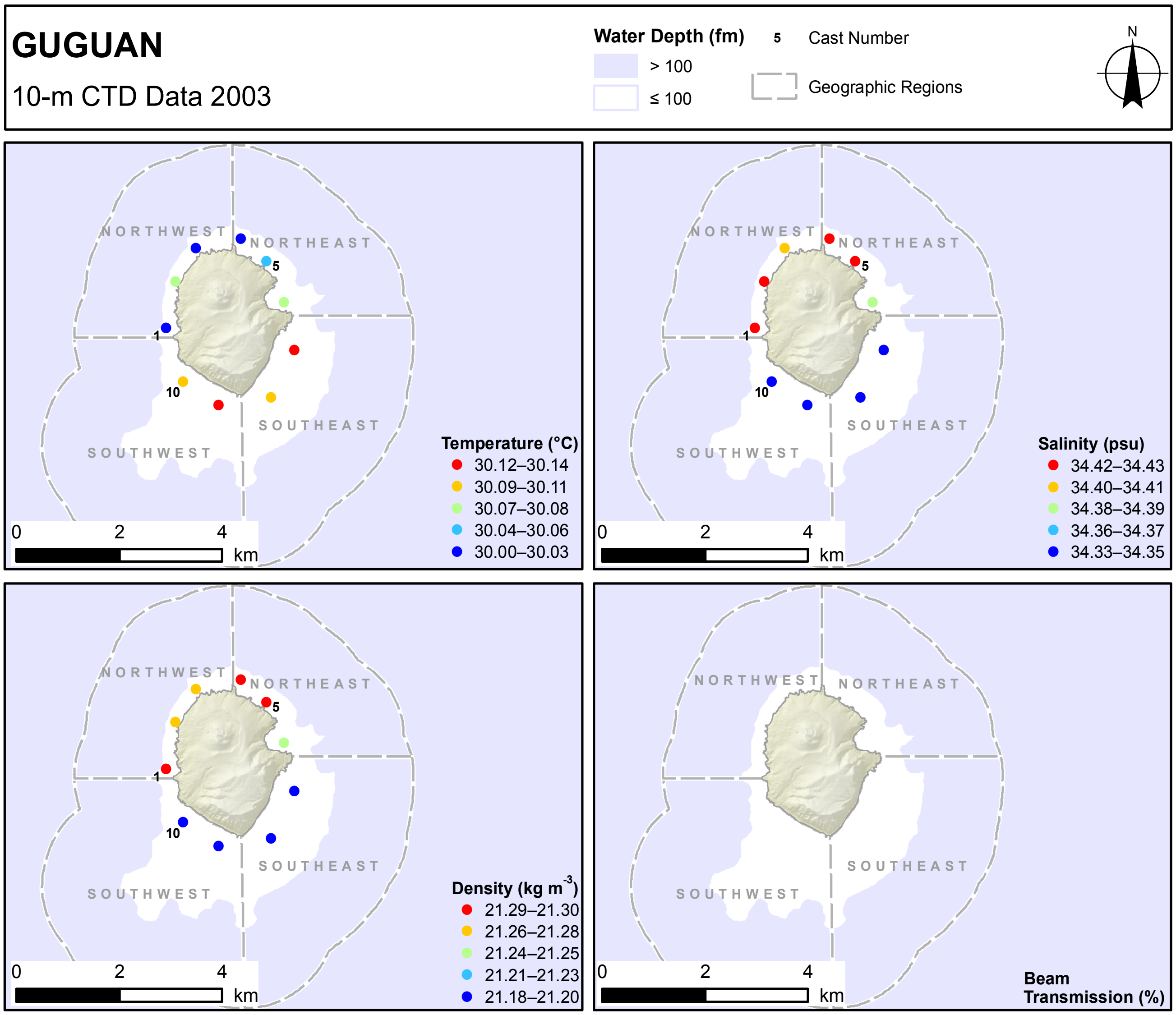


Figure 11.4.1a. Values of *(top left*) water temperature, (*top right*) salinity, and (*bottom left*) density at a 10-m depth from shallow-water CTD casts around Guguan on September 11 during MARAMP 2003.

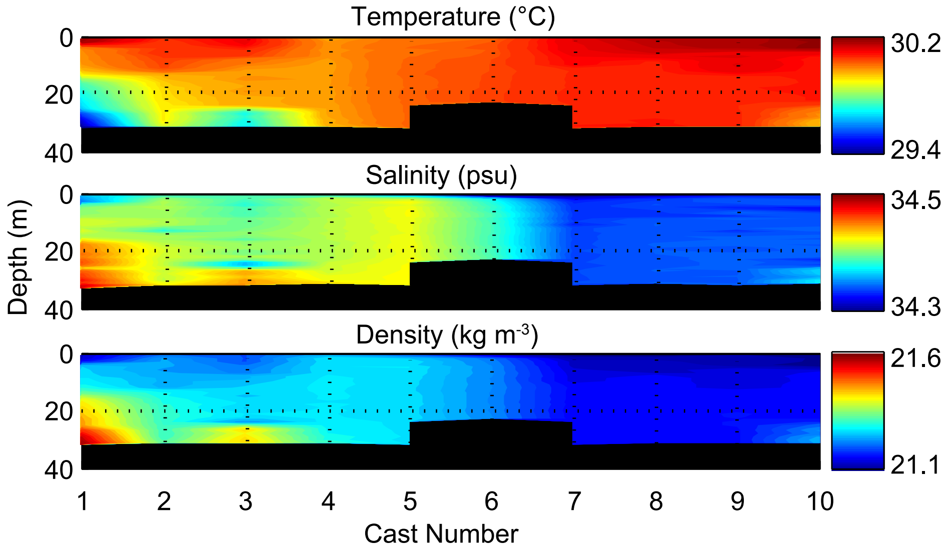


Figure 11.4.1b. Shallow-water CTD cast profiles to a 30-m depth around Guguan on September 11 during MARAMP 2003, including temperature (°C), salinity (psu), and density (kg m^{-3}). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–10 in a clockwise direction around Guguan. For cast locations and numbers around this island in 2003, see Figure 11.4.1a.

2005 Spatial Surveys

During MARAMP 2005, 6 shallow-water CTD casts were conducted in nearshore waters at Guguan on September 5. Temperature, salinity, density, and beam transmission values varied both spatially and vertically at this island. Spatial comparisons of water properties at a depth of 10 m suggest small differences in temperature (0.2°C), salinity (0.04 psu), and density (0.1 kg m^{-3}) values (Fig. 11.4.1c); however, a moderate range in beam transmission (2.7%) values was observed at Guguan. Vertical comparisons of CTD profiles reveal a well-mixed water column, with waters in the northwest region (casts 1–3) slightly cooler and more saline than waters in the southwest (Fig. 11.4.1d). As a result of low water clarity at cast 1 in the northwest region, the difference in beam transmission values at this island was broader than the ranges in values for all other parameters measured.

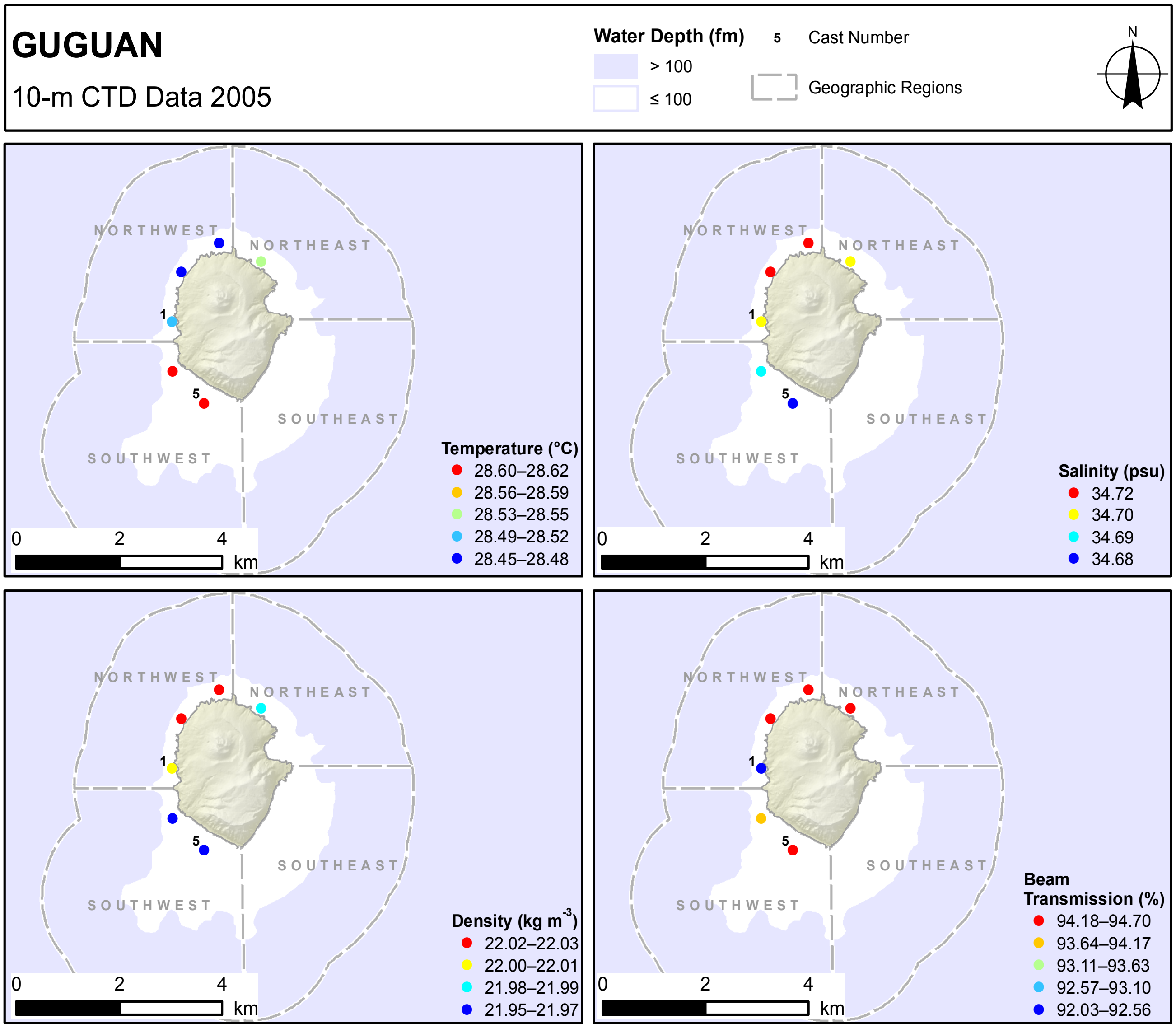


Figure 11.4.1c. Values of (*top left*) water temperature, (*top right*) salinity, (*bottom left*) density, and (*bottom right*) beam transmission at a 10-m depth from shallow-water CTD casts at Guguan on September 5 during MARAMP 2005.

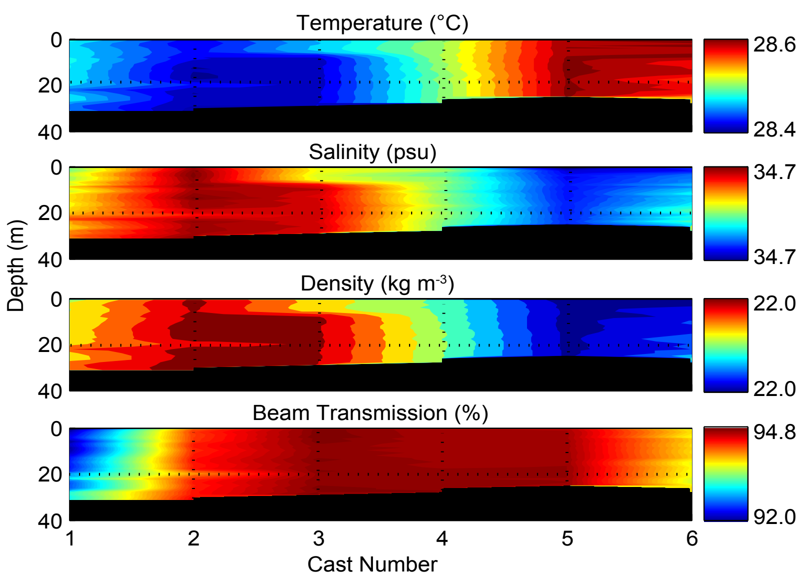


Figure 11.4.1d. Shallow-water CTD cast profiles to a 30-m depth at Guguan on September 5 during MARAMP 2005, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–6 in a clockwise direction around Guguan. For cast locations and numbers around this island in 2005, see Figure 11.4.1c.

2007 Spatial Surveys

During MARAMP 2007, 9 shallow-water CTD casts were conducted in nearshore waters around Guguan on June 8. Temperature, salinity, density, and beam transmission values varied both spatially and vertically around this island. Spatial comparisons of water properties at a depth of 10 m suggest moderate differences in temperature (0.5°C) and salinity (0.3 psu) values and small differences in density (0.1 kg m^{-3}) and beam transmission (< 1%) values. However, temperature, salinity, and beam transmission values were slightly lower in the northwest and southwest regions (casts 1–3, 9) than in the northeast and southeast regions (casts 4–8; Fig. 11.4.1e). Vertical comparisons of CTD profiles reveal water properties with broad differences in temperature (1.5°C), salinity (0.5 psu), density (0.7 kg m^{-3}), and beam transmission (1.8%) values (Fig. 11.4.1f). Well-mixed waters were recorded in the northeast and southeast regions, but stratification with large vertical temperature gradients were recorded in the northwest and southwest regions, particularly in the northwest region where cool, subsurface water was found at depths > 15 m (casts 1–3).

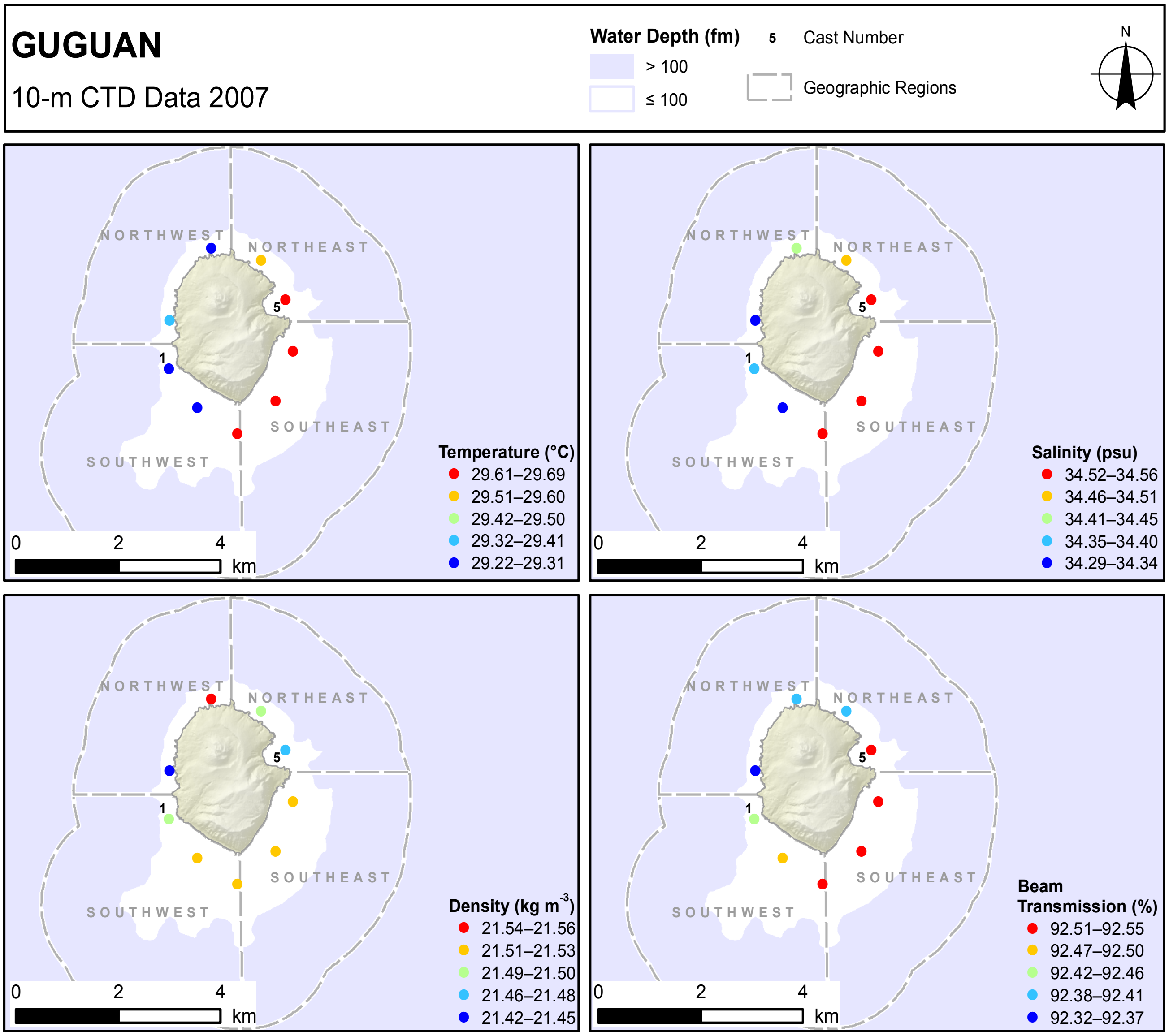


Figure 11.4.1e. Values of (*top left*) water temperature, (*top right*) salinity, (*bottom left*) density, and (*bottom right*) beam transmission at a 10-m depth from shallow-water CTD casts around Guguan on June 8 during MARAMP 2007.

Water samples were collected in concert with swallow-water CTD casts at 3 select locations at Guguan in 2007 to assess water-quality conditions (Fig. 11.4.1g). The following ranges of measured parameters were recorded: chlorophyll-*a* (Chl-*a*), 0.026 –0.071 µg/L; total nitrogen (TN), 0.006–0.083 µM; nitrate (NO_3^-), 00.068 µM; nitrite (NO_2^-), 0.003–0.017 µM; phosphate (PO_4^{3-}), 0.034–0.041 µM; silicate [$Si(OH)_4$], 1.89–1.98 µM. Water-quality parameters generally were observed at the relatively low levels typical of the Western Pacific Warm Pool's oligotrophic, oceanic surface layers, except for silicate, which had high values with the highest concentrations in the southwest region.

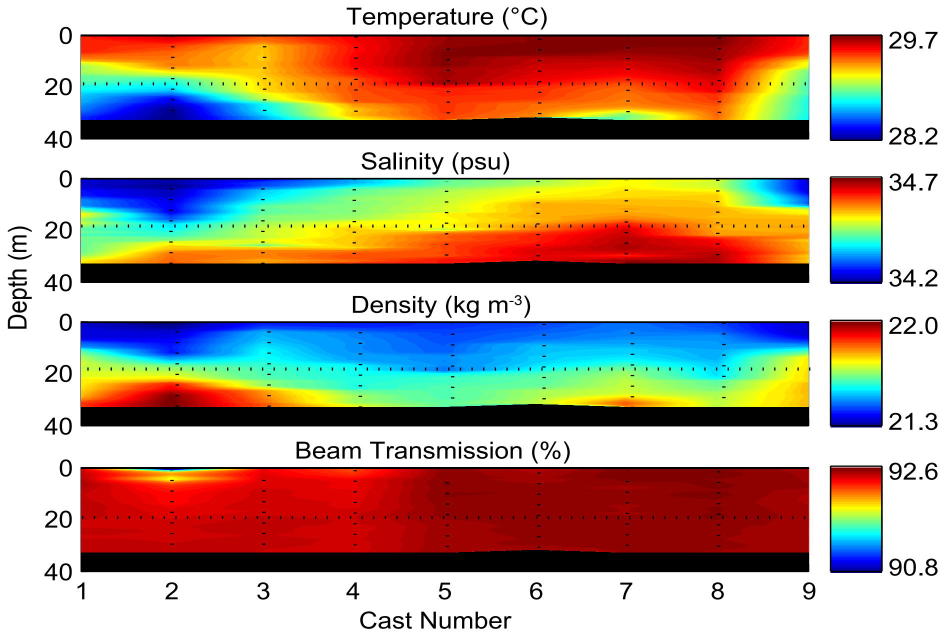


Figure 11.4.1f. Shallow-water CTD cast profiles to a 30-m depth around Guguan on June 8 during MARAMP 2007, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–9 in a clockwise direction around Guguan. For cast locations and numbers around this island in 2007, see Figure 11.4.1e.

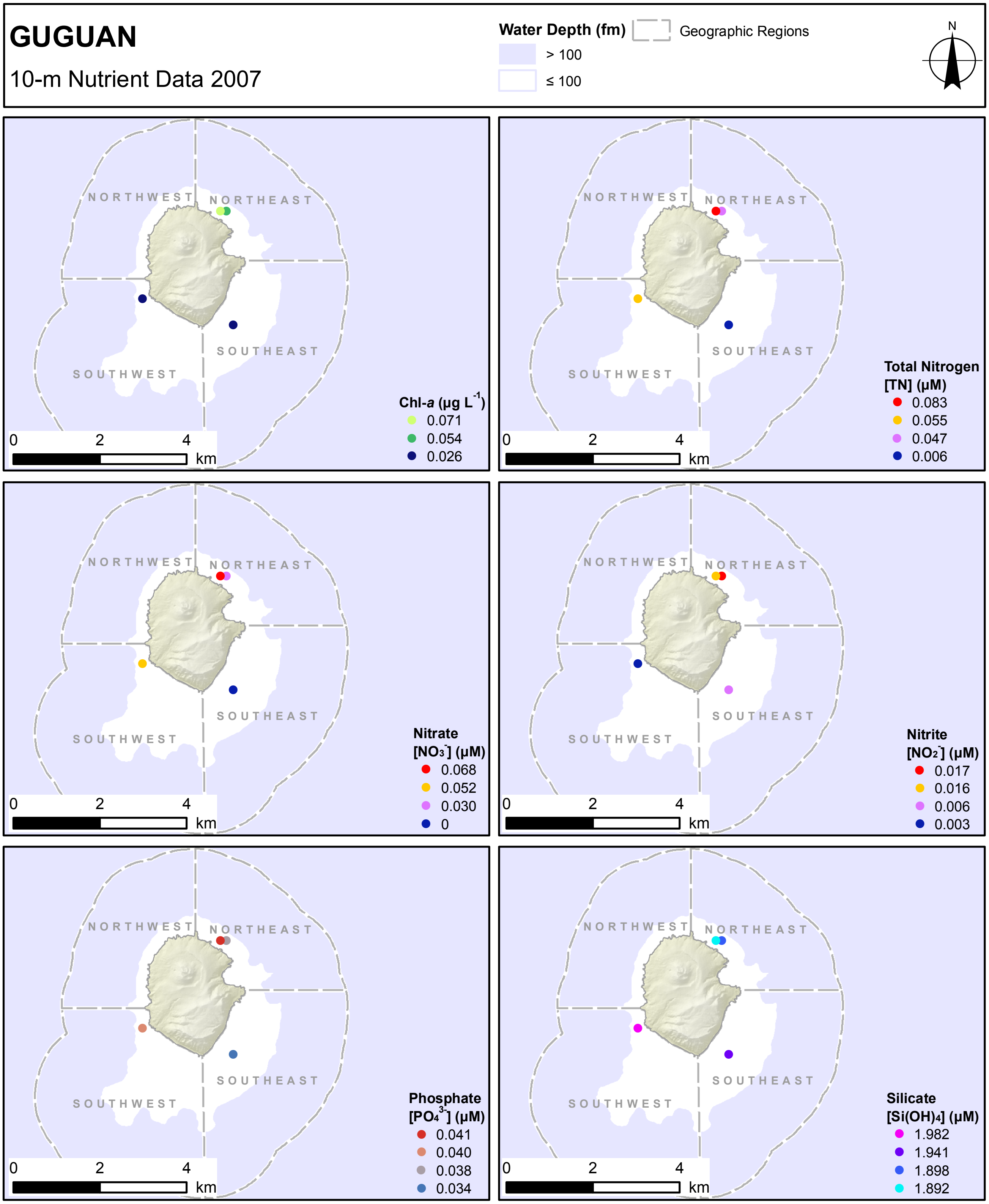


Figure 11.4.1g. Concentrations of (*top left*) Chl-*a*, (*top right*) total nitrogen, (*middle left*) nitrate, (*middle right*) nitrite, (*bottom left*) phosphate, and (*bottom right*) silicate at a 10-m depth, from water samples collected at Guguan on June 8 during MARAMP 2007.

Temporal Comparison

Temporal comparisons between MARAMP survey periods of shallow-water CTD data collected around Guguan during MARAMP 2003, 2005, and 2007 suggest a dynamic physical oceanographic environment. Low spatial variability and moderate vertical variability were observed in 2003 and 2005, and, in 2007, strong spatial variability in water properties was recorded with coldwater (28.2°C; 1.5°C colder than surface waters) intrusions originating from depths > 30 m recorded in the northwest and southwest regions. Data were not collected with respect to a specific tidal cycle, which could be a source of oceanographic variability. Likewise, hydrographic variation between MARAMP survey years is likely a result of differences in season. MARAMP 2007 occurred in June, and MARAMP 2003 and 2005 occurred in September. This change was made to avoid the typhoon season and reduce the probability of weather disruptions.

11.4.2 Time-series Observations

Between 2003 and 2007, subsurface temperature recorders (STRs) were moored at a single location at Guguan to collect time-series observations of temperature, a key oceanographic parameter influencing reef conditions (Fig. 11.4.2a). The location, depth, time frames, and other details about these deployments are provided in Figures 11.4.2a and b

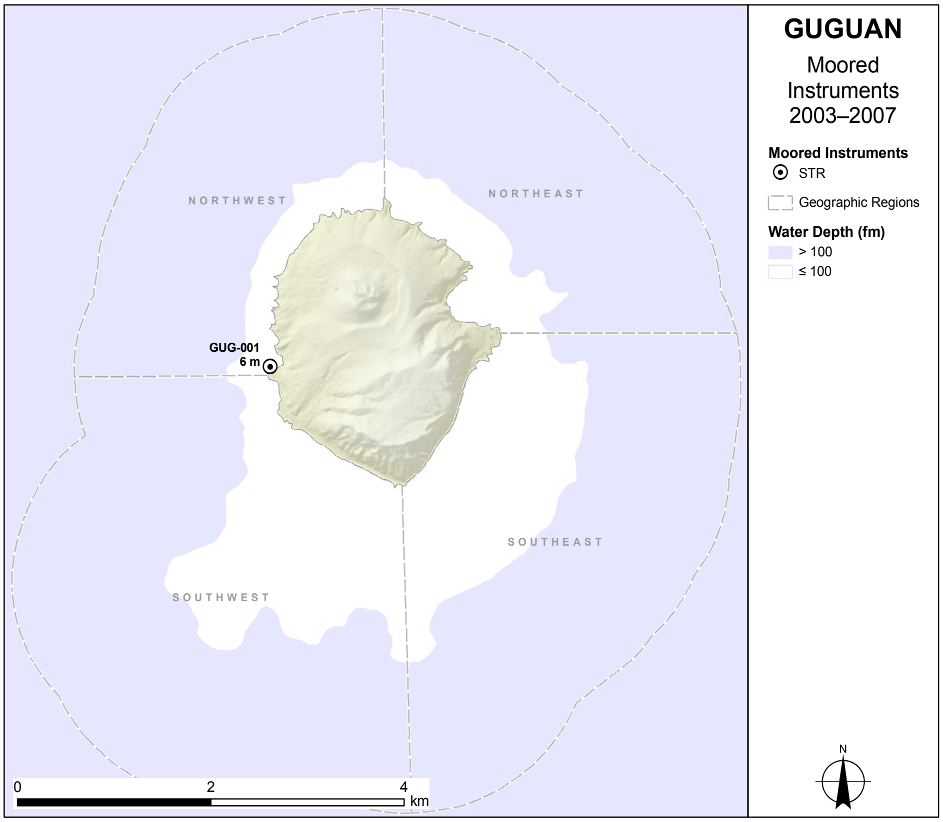


Figure 11.4.2a. Location and depth of the STR deployed at Guguan during MARAMP 2003, 2005, and 2007.

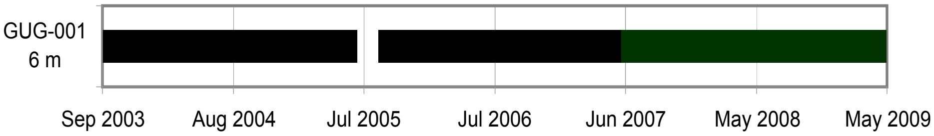
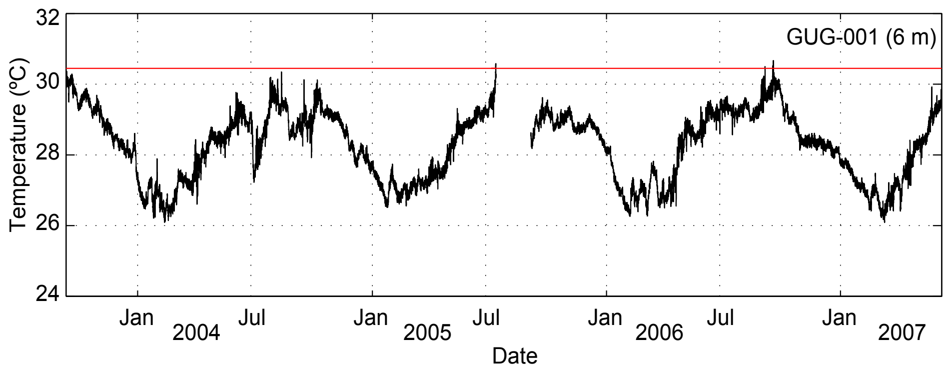


Figure 11.4.2b. Deployment and retrieval timeline and depth of the STR installed at Guguan at a depth of 6 m during the period from September 2003 to May 2009. A solid bar indicates the period for which temperature data were collected by a series of STRs deployed and retrieved at a mooring site. For more information about deployments and retrievals, see Table 11.2b in Section 11.2: "Survey Effort."

Temperature data from STRs deployed a depth of 6 m at a single location in the northwest region show seasonal temperature variability of ~ 4°C (Fig. 11.4.2c). Water temperatures reached 29°C–30°C during the months of June–October and fell to a low of ~ 27°C during the months of January–May. Superimposed with this seasonal temperature variability are frequent intraseasonal fluctuations. For example, recorded temperatures dropped nearly 3°C in July 2004 for ~ 1 week before sharply increasing to typical summertime levels. Similar changes in temperature were observed in September 2004 and in the summer of 2005. Additionally, temperature values exceeded the coral bleaching threshold for the region in July 2005 and September 2006; however, the duration of these events was < 1 d. Diurnal temperature fluctuations were ~ 0.25°C throughout this time series.

Figure 11.4.2c. Time-series observations of temperature over the period between September 2003 and June 2007 collected from 1 STR morning site at a depth of 6 m (see Figure 11.4.2a for mooring location). The red line indicates the coral bleaching threshold, which is defined as 1°C above the maximum climatological mean.



11.4.3 Wave Watch III Climatology

Seasonal wave climatology for Guguan (Fig 11.4.3a) was derived using the NOAA Wave Watch III model for the period of January 1997 to May 2008, and seasons were selected to elucidate waves generated by typhoons, which most frequently occur between the period of August–December (for information about the Wave Watch III model, see Chapter 2: "Methods and Operational Background," Section 2.3.7: "Satellite Remote Sensing and Ocean Modeling"). In terms of consistency, the wave regime during this period was dominated by trade wind swells characterized by frequent (> 30 d per season), short-period (8–10 s), relatively small (2–3 m) wave events originating from the east (~ 80°–90°). Superimposed with these short-period swells were large (> 5 m), long-period (12–16 s) wave events from the south (160°–190°) and south-southeast (200°–210°). These large, episodic waves primarily were generated by typhoons and occurred on annual to interannual time scales. Infrequent (~ 5 d per season), long-period (12–14 s) swells with moderate wave heights (2.5–3.5 m) occurred from any direction, although weighted slightly larger from the south (100°–250°), and likely were associated with episodic, moderate-sized, or distant storms. Similar to the wave regime during typhoon season, the wave climate during the period of February–June (outside the typhoon season) also was characterized by frequent (> 30 d per season) and short-period (~ 8 s) trade wind swells with relatively small wave heights (~ 2 m) originating from the east. Infrequent (< 5 d per season) and long-period (12–14 s) swells with small wave heights (~ 2–3 m) also occurred during this period and originated from any direction.

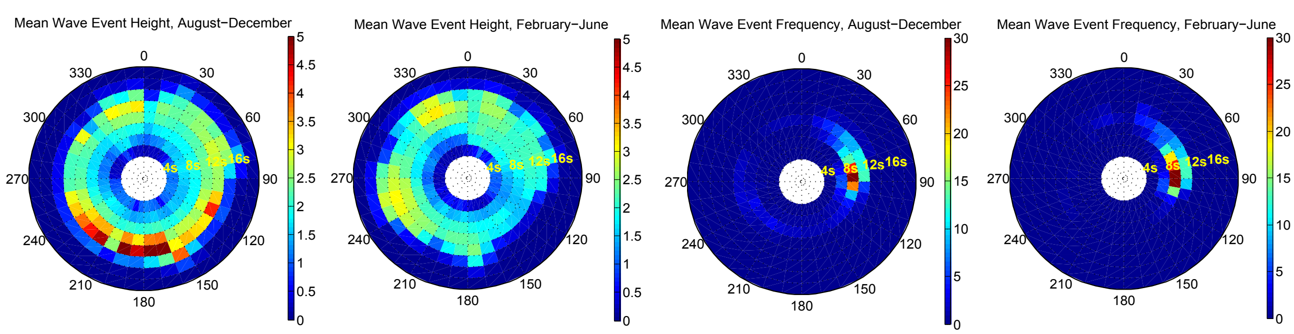


Figure 11.4.3a. NOAA Wave Watch III directional wave climatology for Guguan from January 1997 to May 2008. This climatology was created by binning (6 times daily) significant wave height, dominant period, and dominant direction from a box (1° × 1°) centered on Guguan (17° N, 145° E). Mean significant wave height (*far left and left*), indicated by color scale, for all observations in each directional and frequency bin from August to December (typhoon season) and from February to June. The transition months of January and July are omitted for clarity. Mean number of days (*right and far right*) that conditions in each directional and frequency bin occurred in each season; for example, if the color indicates 30, then, on average, the condition occurred during 30 of the 150 days of that season.

11.5 Corals and Coral Disease

11.5.1 Coral Surveys

Coral Cover and Colony Density

From MARAMP 2003 towed-diver surveys, mean cover of live hard corals on forereef habitats around the island of Guguan was 23% (SE 1.9). Coral cover was highest along the western and eastern coasts with a range of 20.1%–50% over numerous segments (Fig. 11.5.1a, top panel).

From MARAMP 2005 towed-diver surveys, mean cover of live hard corals on forereef habitats at Guguan was 10% (SE 1). Because of weather constraints, 2 towed-diver surveys were conducted at Guguan in 2005, with less complete spatial coverage compared to the survey efforts in 2003 and 2007. Coral cover generally was low on the reef areas surveyed around Guguan in 2005, relative to results from other islands in the Mariana Archipelago (Fig. 11.5.1a, middle panel).

Towed divers during MARAMP 2005 recorded estimates of stressed-coral cover, including corals that were fully bleached (white), pale or discolored, malformed, or stricken with tumors (see Chapter 2: "Methods and Operational Background," Section 2.4.5, "Corals and Coral Disease"). Overall, 0.4% (SE 0.1) of coral cover observed on forereef habitats at Guguan appeared stressed. Stressed-coral cover was low for the majority of reef areas surveyed at Guguan in 2005.

From MARAMP 2007 towed-diver surveys, mean cover of live corals on forereef habitats around Guguan was 27% (SE 2). Coral cover generally was higher in the northern regions than in the southern regions, with the highest coral cover of 34% over 29 segments found during the survey that crossed the border of the northwest and northeast regions (Fig. 11.5.1a, bottom panel). Overall, 0.3% (SE 0.17) of coral cover observed on forereef habitats around Guguan appeared stressed in 2007. Stressed-coral cover was low, compared to other areas surveyed in the Mariana Archipelago, for the majority of reef areas surveyed around Guguan.

During MARAMP 2007, 3 REA benthic surveys using the line-point-intercept method were conducted on forereef habitats at Guguan. Site-specific estimates of live-hard-coral cover from these surveys ranged from 8.8% to 20.6% with an overall sample mean of 15.4% (SE 3.5). Live coral cover was highest at REA site GUG-01 in the southeast region and lowest at GUG-02 in the southwest region (Fig. 11.5.1b, bottom panel).

During MARAMP 2003, 3 REA benthic surveys using the quadrat method on forereef habitats at Guguan documented 356 coral colonies within a total survey area of 11.25 m^2. Site-specific colony density ranged from 19.7 to 41.3 colonies m^{-2} with an overall sample mean of 31.6 colonies m^{-2} (SE 6.3). The highest colony density was recorded at GUG-02 in the southwest region, and the lowest colony density was observed at GUG-03 in the northwest region (Fig. 11.5.1b, top panel).

During MARAMP 2007, 3 REA benthic surveys using the quadrat method on forereef habitats at Guguan documented 557 coral colonies within a total survey area of 12 m^2. Site-specific colony density ranged from 43 to 48.8 colonies m^{-2} with an overall sample mean of 46.4 colonies m^{-2} (SE 1.8). The highest colony density was recorded at GUG-01 in the southeast region. Colony density was similarly high at GUG-03 in the northwest region and slightly lower at GUG-02 in the southwest region (Fig. 11.5.1b, bottom panel).

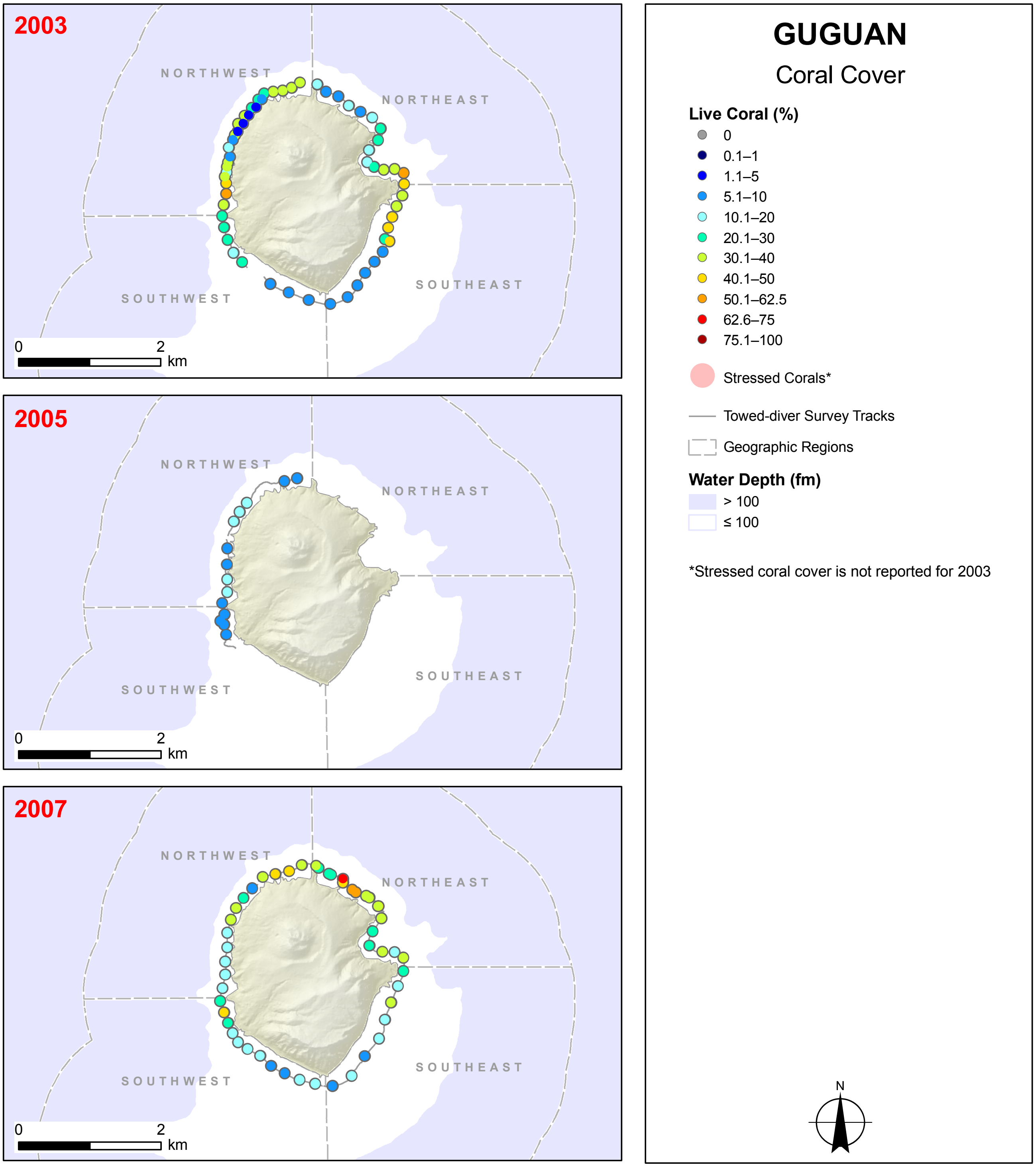


Figure 11.5.1a. Cover (%) observations of live and stressed hard corals from towed-diver benthic surveys of forereef habitats conducted around Guguan during MARAMP 2003, 2005, and 2007. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m^2). Pink symbols are shown only for segments where estimates of stressed-coral cover were > 10%. Stressed-coral cover was measured as a percentage of overall coral cover in 2005 and 2007.

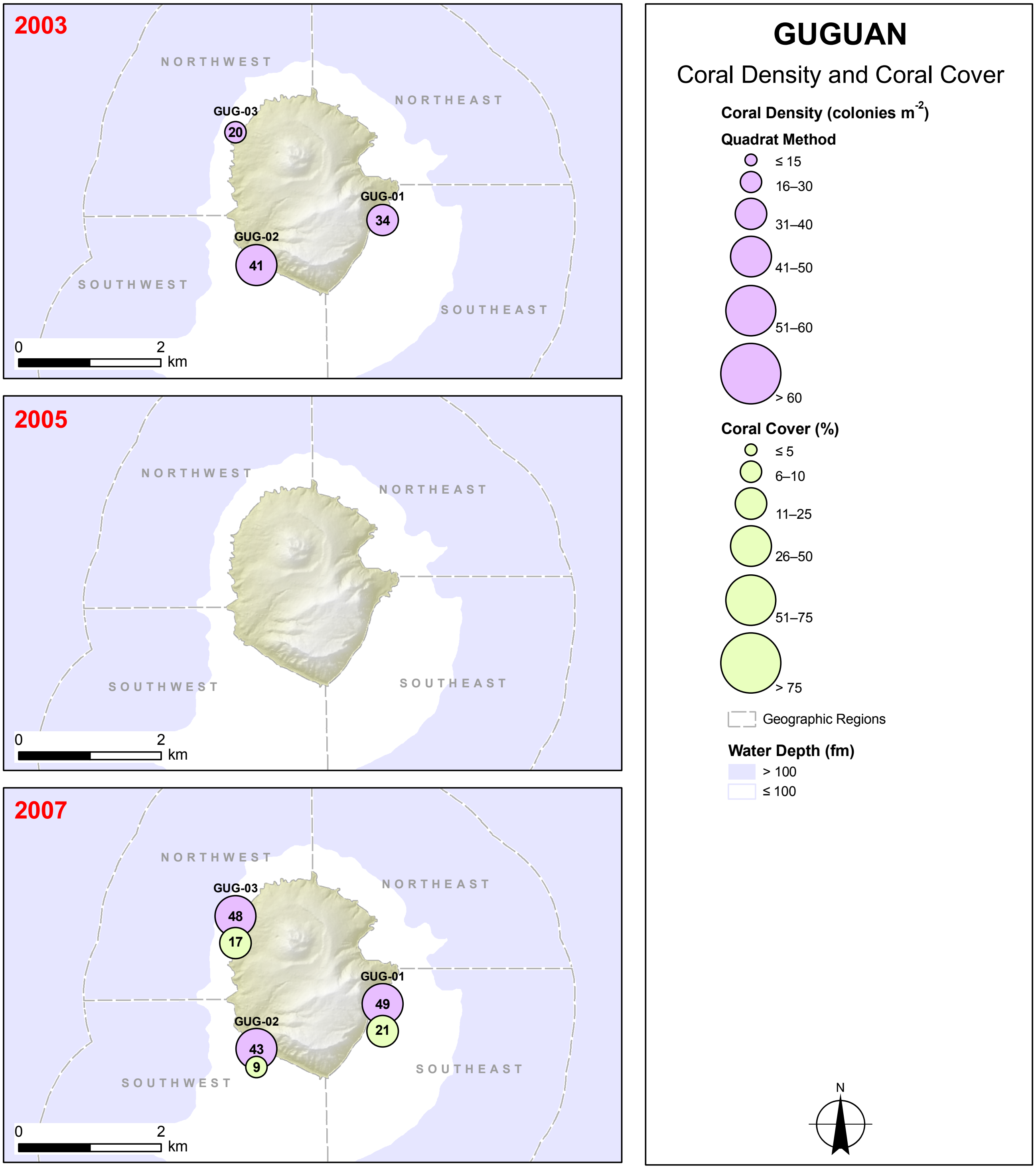


Figure 11.5.1b. Colony-density (colonies m^{-2}) observations of live hard corals from REA benthic surveys of forereef habitats conducted at Guguan during MARAMP 2003 and 2007, and cover (%) observations of live corals from REA benthic surveys during MARAMP 2007. Values are provided within each symbol. The quadrat method was used in 2003 and 2007 to assess coral-colony density.

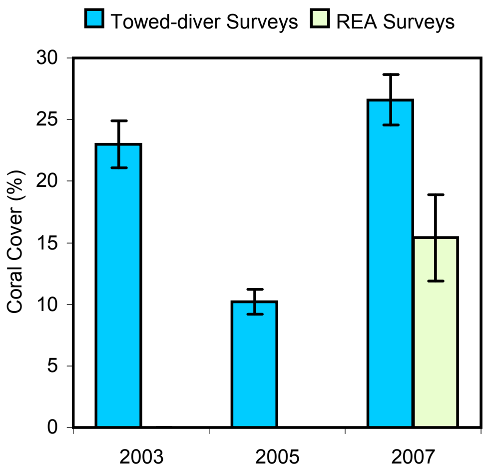


Figure 11.5.1c. Temporal comparison of mean live-coral-cover (%) values from REA and towed-diver benthic surveys conducted on forereef habitats around Guguan during MARAMP 2003, 2005, and 2007. No REA surveys using the line-point-intercept method were conducted around Guguan in 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

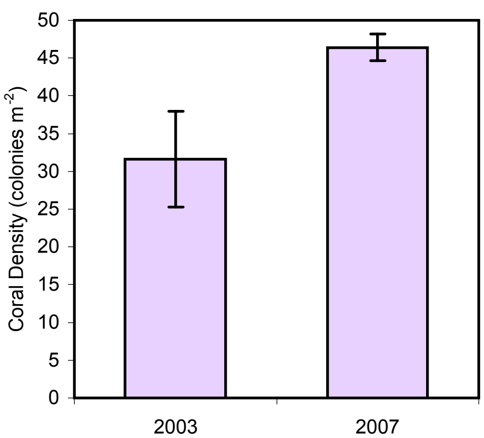


Figure 11.5.1d. Temporal comparison of mean coral-colony densities (colonies m^{-2}) from REA benthic surveys conducted on forereef habitats at Guguan during MARAMP 2003 and 2007. Guguan was not surveyed for colony density in 2005. The quadrat method was used in 2003 and 2007 to measure coral-colony density. Error bars indicate standard error (± 1 SE) of the mean.

Islandwide mean cover of live corals estimated from towed-diver surveys of forereef habitats was 22.6% (SE 1.9) in 2003, 10.2% (SE 1.0) in 2005, and 26.6% (SE 2.0) in 2007 (Fig. 11.5.1c). Survey effort in 2005 primarily was limited to the northwest region, where coral cover was low; thus, average cover was lower in 2005 than in 2003 and 2007. Guguan was not surveyed for coral cover using the line-point-intercept method in 2003 or 2005. For the 3 REA sites surveyed using the line-point-intercept method in 2007, overall mean coral cover was 15.4% (SE 3.5).

Overall mean coral-colony density from REA benthic surveys of forereef habitats at Guguan increased from 31.6 colonies m^{-2} (SE 6.3) in 2003 to 46.4 colonies m^{-2} (SE 1.8) in 2007 (Fig. 11.5.1d). This rise in colony density could have resulted from increased recruitment or fragmentation of existing colonies. The quadrat method was used in both 2003 and 2007 to assess coral colony density at Guguan.

Coral Generic Richness and Relative Abundance

Three REA benthic surveys of forereef habitats were conducted using the quadrat method at Guguan during MARAMP 2003. At least 18 coral genera were observed. Generic richness ranged from 14 to 15 with a mean of 14.7 (SE 0.3) coral genera per site (Fig. 11.5.1e, top panel). No strong spatial pattern in generic diversity was seen.

Pavona, Favia, and *Leptastrea* were the most numerically abundant genera, contributing 23.1%, 12.6%, and 12% to the total number of colonies enumerated at Guguan in 2003. All other genera individually contributed < 10% of the total number of colonies. The genus *Pavona* dominated the coral fauna at all 3 sites surveyed, accounting for 22%, 29.7%, and 17.6% to the total number of colonies enumerated at GUG-01, GUG-02, and GUG-03.

Three REA benthic surveys of forereef habitats were conducted using the quadrat method at Guguan during MARAMP 2007. At least 22 coral genera were observed. Generic richness ranged from 16 to 20 with a mean of 17.7 (SE 1.2) coral genera per site (Fig. 11.5.1e, bottom panel). The highest generic diversity was seen at GUG-01 in the southeast region, and the lowest generic diversity was recorded at GUG-02 in the southwest region.

Favia, Pavona, Pocillopora, and *Leptastrea* were the most numerically abundant genera, contributing 23.3%, 22.1%, 11.7%, and 11.5% of the total number of colonies enumerated at Guguan in 2007. All other genera individually accounted for < 10% of the total number of colonies. The genera *Favia* and *Pavona* co-dominated at GUG-01, each contributing 26.2% of the total number of colonies observed at that site. As in 2003, the genus *Pavona* dominated at GUG-02, accounting for 23.8% of the total number of colonies recorded at that site, but the genus *Favia* dominated at GUG-03, contributing 26.8% of the total number of colonies observed at that site.

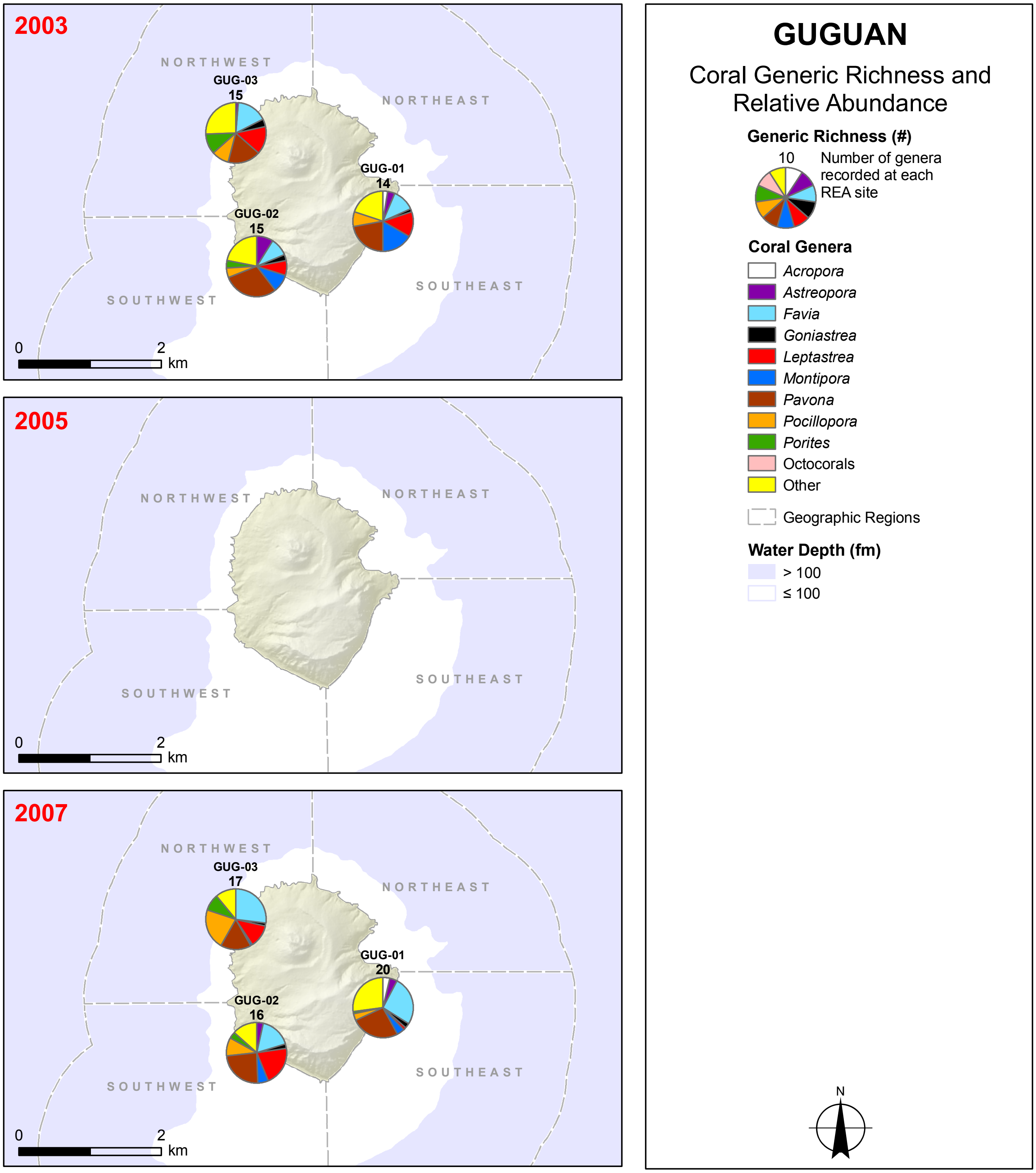


Figure 11.5.1e. Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted at Guguan during MARAMP 2003 and 2007. Guguan was not surveyed for generic richness in 2005. The pie charts indicate percentages of relative abundance of key coral genera. The quadrat method was used in both years to survey coral genera.

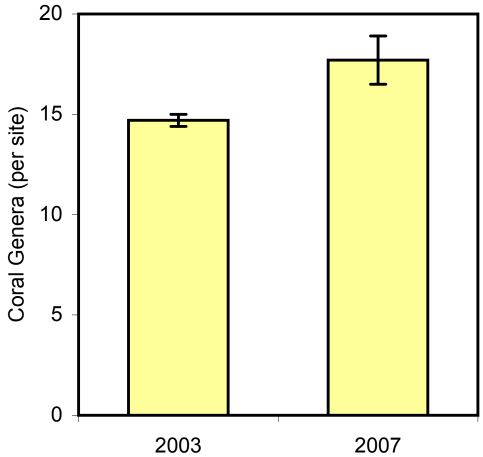


Figure 11.5.1f. Temporal comparison of overall mean numbers of coral genera per site from REA benthic surveys conducted on forereef habitats at Guguan during MARAMP 2003 and 2007. Guguan was not surveyed for generic richness in 2005. The quadrat method was used in both years to survey coral genera. Error bars indicate standard error (± 1 SE) of the mean.

Site-specific estimates of generic richness from MARAMP 2003 and 2007 ranged from 14 to 20 on forereef habitats. Overall sample means of generic richness were lower in 2003 than in 2007 with 14.7 (SE 0.3) in 2003 to 17.7 (SE 1.2) in 2007 (Fig. 11.5.1f). This change in estimates resulted from the observation of a few colonies of 4 genera in 2007 (*Echinopora, Leptoria, Hydnophora*, and *Stylocoeniella*) that were not recorded in 2003.

During the 2 survey years, 23 coral genera were observed on forereef habitats at Guguan. The genera *Pavona*, *Favia*, and *Leptastrea* were important components of the coral fauna, accounting for > 10% of the total number of colonies enumerated at Guguan in both survey years. The genus *Pavona* was the most abundant taxon in 2003 and the second-most abundant taxon in 2007, contributing 23.1% and 22.1% of the total number of colonies recorded. The genus *Favia* was the most abundant taxon in 2007 and the second-most abundant in 2003, contributing 23.3% and 12.6% of the total number of colonies enumerated. *Leptastrea* was the third-most abundant taxon in 2003 and the fourth-most abundant taxon in 2007, contributing 12% and 11.5% of the total number of colonies. The contribution of the genus *Pocillopora* slightly exceeded that of the genus *Leptastrea* in 2007, contributing 11.7% of the total number of colonies. All other taxa contributed < 10% of the total number of colonies enumerated at Guguan in both survey years.

Coral Size-class Distribution

During MARAMP 2003, 3 REA benthic surveys of forereef habitats were conducted at Guguan using the quadrat method. The coral size-class distribution from these surveys shows that the majority (55.8%) of corals had maximum diameters ≤ 5 cm (Fig. 11.5.1g, top panel). The next 3 size classes (6–10, 11–20, and 21–40 cm) accounted for 29.9%, 9.1%, and 5.2% of colonies recorded. No colonies with maximum diameters > 40 cm were recorded. At GUG-01 and GUG-02 in the southeast and southwest regions, a majority (> 63%) of corals was in the smallest size class (≤ 5 cm), and at GUG-03 in the northwest region only 40.5% of corals had maximum diameters ≤ 5 cm.

During MARAMP 2007, 3 REA benthic surveys of forereef habitats were conducted at Guguan using the quadrat method. The coral size-class distribution from these surveys shows that the majority (83%) of corals had maximum diameters ≤ 5 cm, and only 0.3% had maximum diameters > 40 cm (Fig. 11.5.1g, bottom panel). Corals in the size classes 6–10, 11–20, and 21–40 cm, accounted for 13.7%, 1.5%, and 1.4% of colonies recorded. At each REA site, a majority (> 69%) of corals were in the smallest size class (≤ 5 cm).

Site-specific and overall distributions of estimated coral size classes on forereef habitats at Guguan are affected by inherent biases in the method used to census and size corals. Corals whose center fell within the borders of a quadrat (50 × 50 cm) were tallied and measured in 2 planar dimensions to the nearest centimeter. Fewer large colonies than small colonies can fall within a quadrat. This bias can contribute to higher counts of colonies in the smallest size classes and lower counts of colonies in the largest size classes compared to the actual relative colony densities. At each site, 15 or 16 such quadrats were examined (total survey area = 3.75 or 4 m^2), enabling observers to closely inspect and record each coral colony within the quadrat. For more on this survey method, see Chapter 2, "Methods and Operational Background, Section 2.4.5: "Corals and Coral Disease."

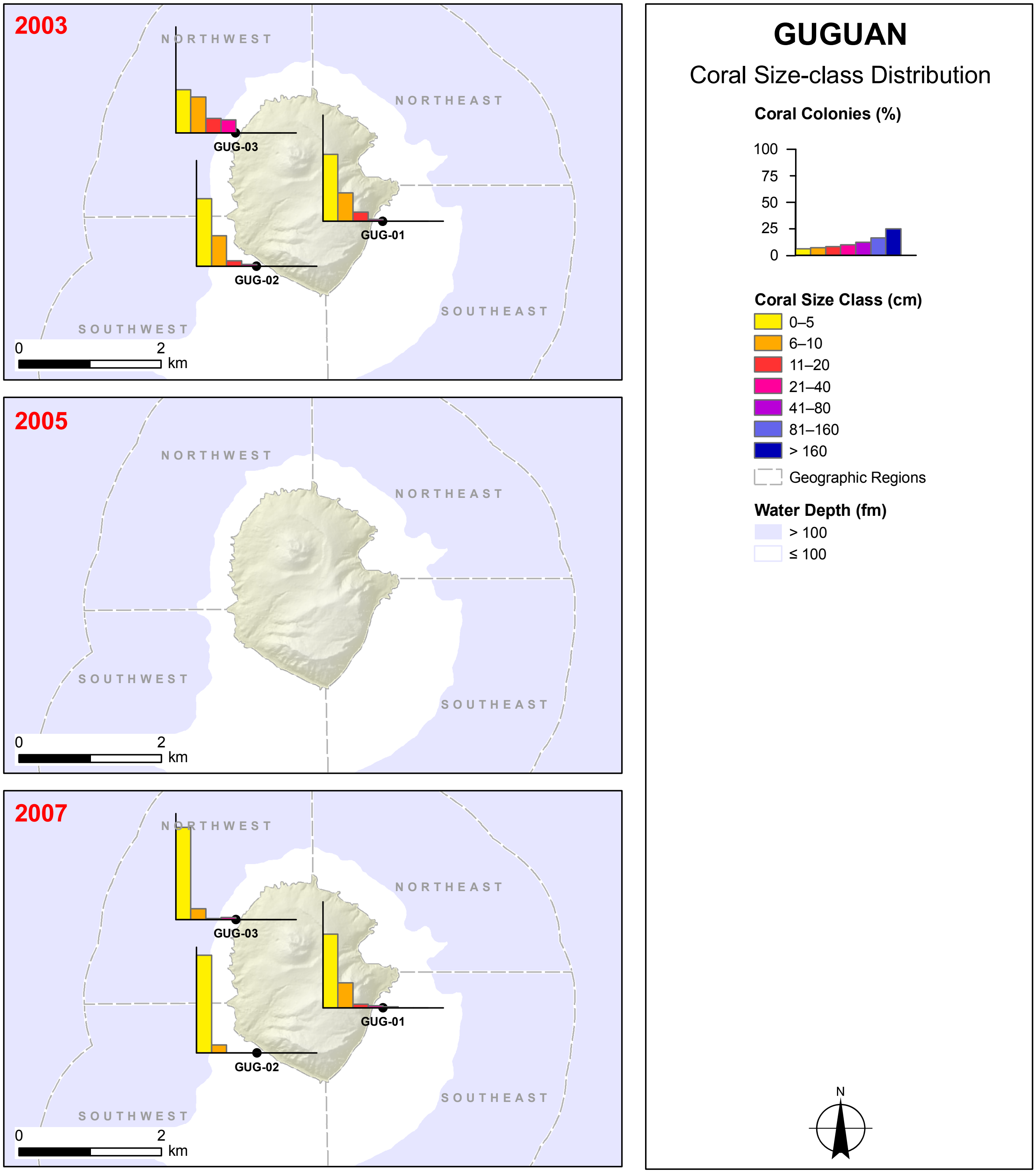
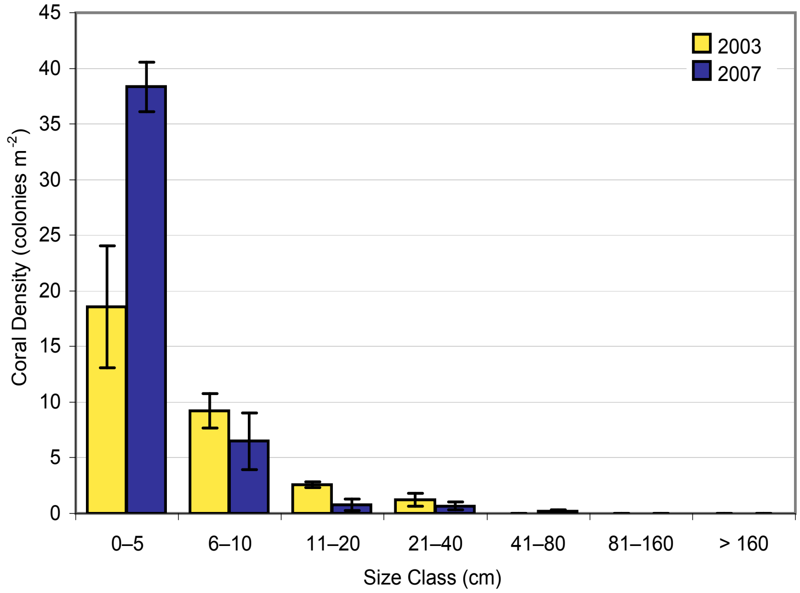


Figure 11.5.1g. Size-class distributions of hard corals from REA benthic surveys of forereef habitats conducted at Guguan during MARAMP 2003 and 2007. Guguan was not surveyed for coral size-class distribution in 2005. The observed size classes are color coded in a size-frequency chart at each REA site. The quadrat method was used in both survey years to size corals.

During MARAMP 2003 and 2007, the majority of coral colonies were in the smallest size class (0–5 cm) with about twice as many small corals observed in 2007 as seen in 2005 (Fig. 11.5.1h). The overall mean proportions of colonies at Guguan that fell in the smallest size class increased, from 55.3% in 2003 to 83% in 2007, as did the values for each of the 3 sites surveyed in both years. Concordantly, the overall mean proportion of colonies in all other size classes decreased between 2003 and 2007, as did all site-specific proportions. This observed shift toward the smallest size class may be a result of recruitment, fragmentation of existing colonies, or both. Minor variation between overall and site-specific size-class distributions recorded in 2003 and 2007 likely result from chance differences in the placement of individual quadrats.

Figure 11.5.1h. Mean coral-colony densities (colonies m^{-2}) by size class from REA benthic surveys of forereef habitats at Guguan during MARAMP 2003 and 2007. Guguan was not surveyed for coral size-class distribution in 2005. The quadrat method was used in both survey years to size corals. Error bars indicate standard error (± 1 SE) of the mean.

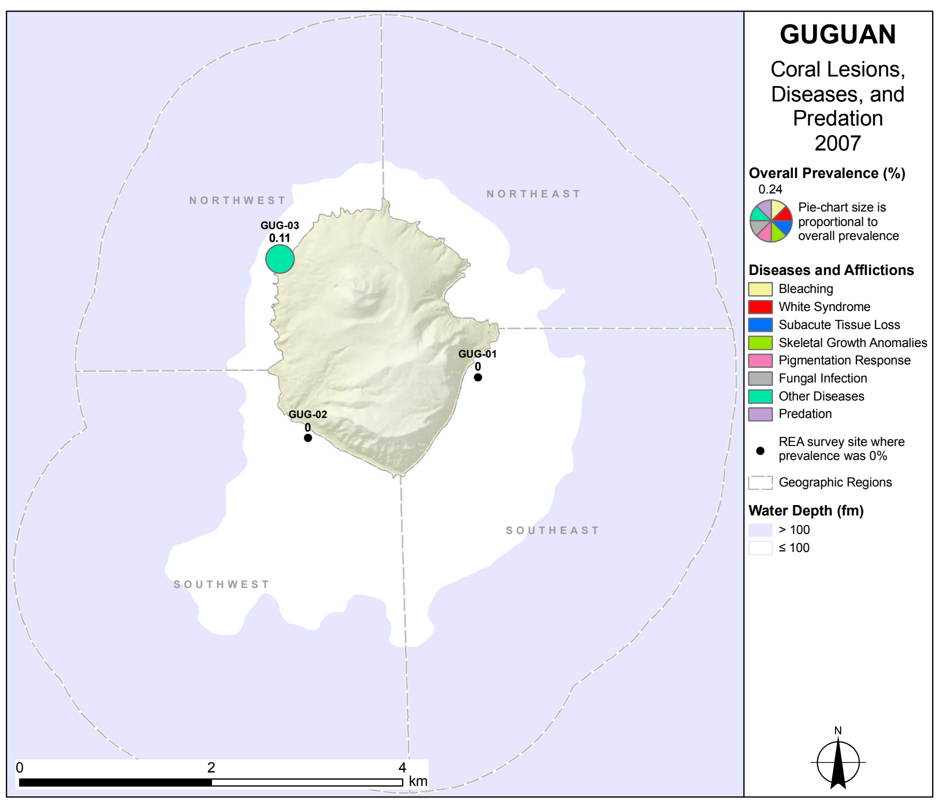


11.5.2 Surveys for Coral Disease and Predation

During MARAMP 2007, REA benthic surveys for coral disease and predation were conducted at 3 sites on forereef habitats at Guguan, covering a total area of 700 m^2. Surveys detected 8 cases of disease, translating to an overall mean prevalence of 0.04% (SE 0.02). Coral-colony counts at all REA sites at Guguan were conducted using the quadrat method, resulting in high coral-colony densities and, therefore, low disease prevalence values, relative to the levels found at sites at other islands surveyed using the belt-transect method.

One disease condition was observed at Guguan: an infestation by the encrusting sponge *Terpios*. Of the 3 sites surveyed, only GUG-03 contained disease (Fig. 11.5.2a). Cases of *Terpios* infestation were detected on a variety of massive and encrusting corals, including *Goniastrea*, *Favia*, *Porites*, and *Pavona*. No signs of predation scars from crown-of-thorns seastars (*Acanthaster planci*) or corallivorous snails were observed at the sites surveyed.

Figure 11.5.2a. Overall prevalence (%) observations of coral diseases and predation from REA benthic surveys of forereef habitats conducted at Guguan during MARAMP 2007. Prevalence was computed based on the estimated total number of coral colonies within the area surveyed for disease at each REA site.



11.6 Algae and Algal Disease

11.6.1 Algal Surveys

Algal Cover: Macroalgae and Turf Algae

From MARAMP 2003 towed-diver surveys, mean macroalgal cover on forereef habitats around the island of Guguan was 45% (SE 2.3). Obsservations of macroalgal cover in 2003 included both macroalgae and turf algae. The survey with the highest mean macroalgal cover of 64%, within a range of 50.1%–75%, occurred in the northwest region (Fig. 11.6.1a, top left panel) over habitat predominantly of continuous reef and medium-high to high complexity. The second-highest mean macroalgal cover from a towed-diver survey was 59%, recorded in the northeast region. The survey with the lowest mean macroalgal cover of 26%, within a range of 10.1%–50%, occurred along the central part of the west coast of Guguan.

TOAD surveys completed at Guguan during MARAMP 2003 were conducted at depths of 40–270 m. Analyses of TOAD video footage obtained from 2 surveys in the southwest region suggested very few macroalgae in that area (Fig. 11.6.1a, top left panel). Macroalgae were more common in a third survey, which occurred also in the southwest region and between the other 2 surveys, with cover in a range of 20%–100%, at least as seen in a quarter of video frames.

From MARAMP 2005 towed-diver surveys, mean macroalgal cover on forereef habitats at Guguan was 10% (SE 3.4). As a result of a large, northwestern swell and 20-kt winds, only 3 towed-diver surveys were attempted, all in the southwest and northwest regions. Only 1 survey occurred in waters shallow enough to record benthic composition data for the majority of its survey segments. This survey ran along the central part of the west coast in both the northwest and southwest region, recording mean macroalgal cover of 3.1%, within a range of 0%–10% (Fig. 11.6.1a, middle left panel).

From MARAMP 2007 towed-diver surveys, mean macroalgal cover on forereef habitats around Guguan was 20% (SE 1.4). The survey with the highest mean macroalgal cover of 23%, within a range of 10.1%–40%, occurred in the southwest region over habitat of medium to medium-high complexity (Fig. 11.6.1a, bottom left panel). The lowest mean macroalgal cover from a towed-diver survey was 13.7%, recorded around the northern coast crossing the border between the northwest and northeast regions.

During MARAMP 2007, 3 REA benthic surveys of forereef habitats at Guguan were conducted using the line-point-intercept method. Site-specific estimates of macroalgal cover from these surveys ranged from 0% to 8.8% with an overall mean of 4% (SE 2.6). The REA survey with the highest macroalgal cover occurred in the southwest region at REA site GUG-02 (Fig. 11.6.1b). No macroalgae were recorded in the northwest region at GUG-03.

Turf-algal cover from these REA benthic surveys in 2007 ranged from 51% to 80.4% with an overall mean of 62% (SE 9.4).The survey with the highest turf-algal cover occurred in the northwest region at GUG-03 (Fig. 11.6.1b). The lowest turf-algal cover was recorded in the southwest region at GUG-02.

Algal Cover: Crustose Coralline Red Algae

From MARAMP 2003 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Guguan was 17% (SE 1.3). The survey with the highest mean crustose-coralline-red-algal cover of 30%, within a range of 5.1%–40%, occurred in the northwest region (Fig. 11.6.1a, top right panel). The lowest mean cover of crustose coralline red algae from a towed-diver survey was 4.7%, within a range of 1.1%–20%, recorded around the southern coast crossing the border between the southeast and southwest regions.

From MARAMP 2005 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats at Guguan was 15% (SE 4.4). The only towed-diver survey with observations from more than 5 segments was completed along the central part of the west coast with mean crustose coralline-red-algal cover of 2.5%, within a range of 1.1%–5% (Fig. 11.6.1a, middle right panel).

From MARAMP 2007 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Guguan was 13% (SE 1.1). The survey with the highest mean crustose-coralline-red-algal cover of 18.5%, within a range of 5.1%–40%, occurred around the northern coast crossing the border between the northwest and northeast regions

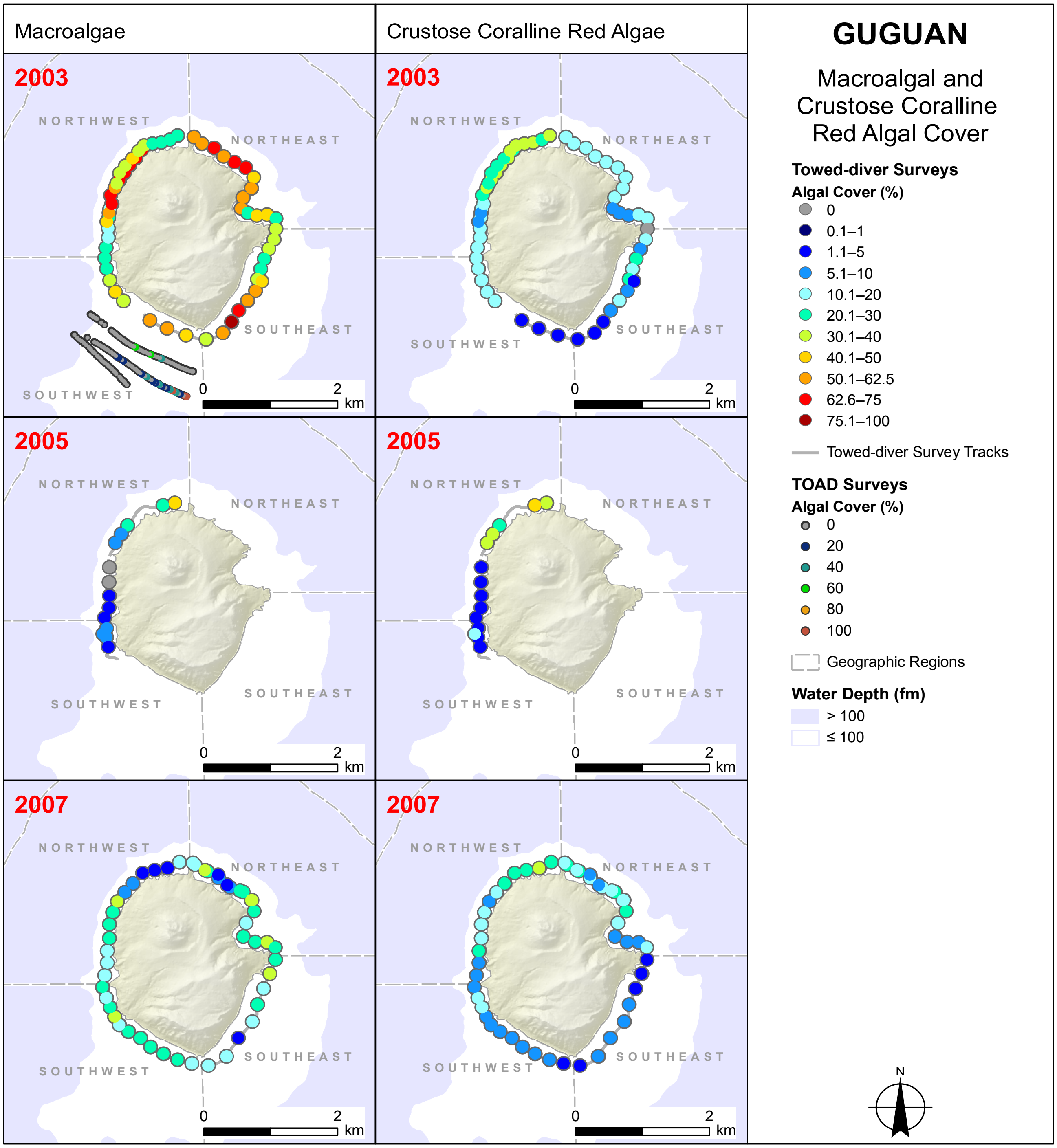


Figure 11.6.1a. Cover (%) observations for macroalgae and crustose coralline red algae from towed-diver benthic surveys of forereef habitats conducted around Guguan during MARAMP 2003, 2005, and 2007. Each large, colored point represents an estimate over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m^2). The 2003 macroalgal panel shows observations of both macroalgae and turf algae (towed-diver surveys included turf algae only during MARAMP 2003). In this panel, each small, colored point represents an estimate of algal cover from TOAD surveys.

(Fig. 11.6.1a, bottom right panel). The lowest mean cover of crustose coralline red algae from a towed-diver survey was 6.2%, recorded in the southeast region.

During MARAMP 2007, 3 REA benthic surveys of forereef habitats around Guguan were conducted using the line-point-intercept method. Site-specific estimates of crustose-coralline-red-algal cover ranged from 0% to 2.9% with an overall mean of 2% (SE 0.9). The REA survey with the highest crustose-coralline-red-algal cover occurred in the southeast region at GUG-01 (Fig. 11.6.1b). No crustose coralline red algae were recorded at GUG-03 in the northwest region.

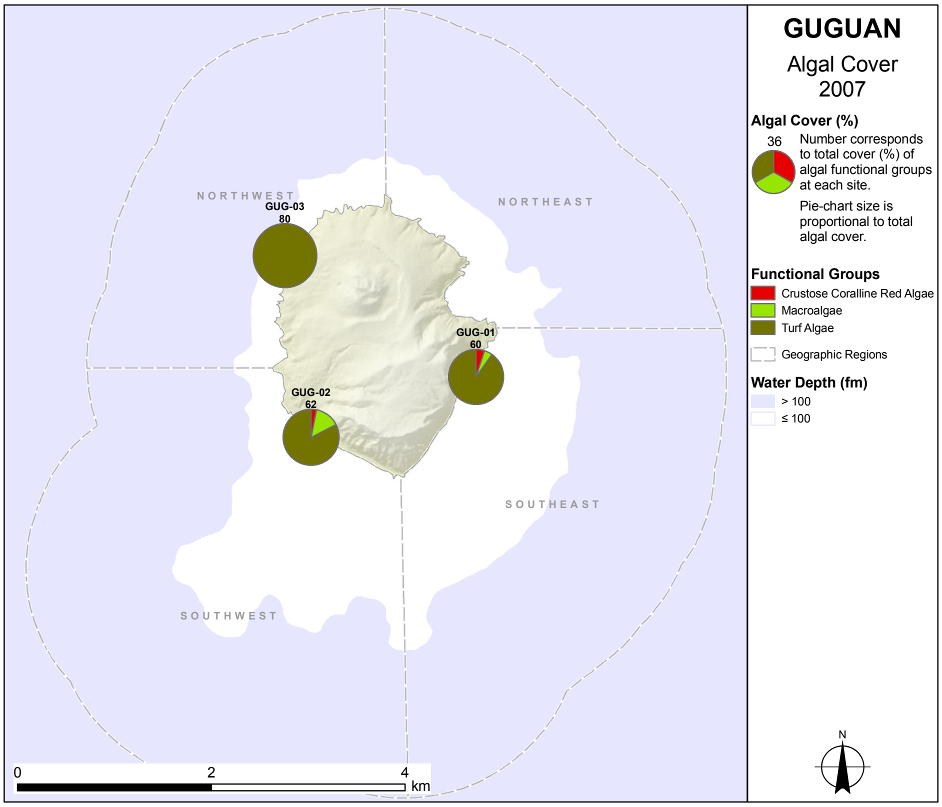


Figure 11.6.1b. Observations of algal cover (%) from REA benthic surveys of forereef habitats conducted using the line-point-intercept method around Guguan during MARAMP 2007. The pie charts indicate algal cover by functional group, and values of total algal cover are provided above each symbol.

Algal Cover: Temporal Comparison

Between MARAMP 2005 and 2007, overall mean cover of macroalgal populations around Guguan, based on towed-diver surveys of forereef habitats, was higher in 2007 than in 2005 (Fig. 11.6.1c). Mean macroalgal cover ranged from 45% (SE 2.3) in 2003 to 10% (SE 3.4) in 2005 and 20% (SE 1.4) in 2007. When considering survey results, keep in mind that turf algae were included, along with macroalgae, in towed-diver surveys of macroalgal cover only in 2003. Other factors, such as a change in season between survey periods, could have contributed to differences in algal cover (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

Between survey years, no towed-diver-survey area consistently had the highest or lowest macroalgal cover. The highest macroalgal cover of 64% from a towed-diver survey in 2003 was recorded in the northwest region. Yet surveys in the same vicinity in 2005 and 2007 recorded much lower macroalgal cover with means of 3% and 20%; this decrease is likely a result of the inclusion of turf algae in 2003.

Islandwide estimates of crustose coralline red algae around Guguan, based on towed-diver surveys of forereef habitats, decreased slightly from MARAMP 2003 to 2007 (Fig. 11.6.1c). Mean cover varied from 17.1% (SE 1.3) in 2003 to 12.9% (SE 1.1) in 2007. For the 3 MARAMP survey years, the highest mean crustose-coralline-red-algal cover from a towed-diver survey occurred in the northwest region. In 2003 and 2007, the lowest mean crustose-coralline-red-algal cover occurred along the southern shoreline.

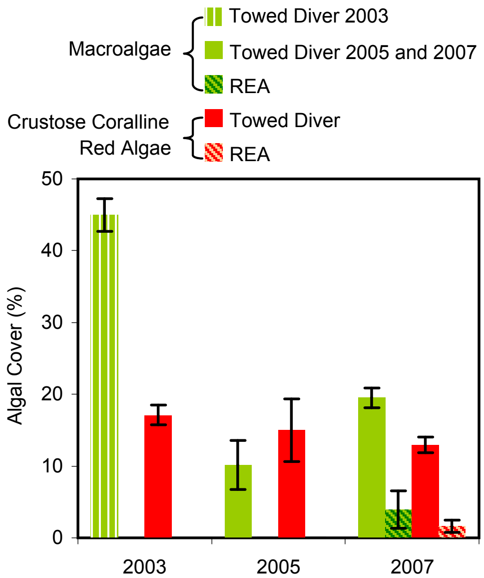


Figure 11.6.1c. Temporal comparison of algal-cover (%) values from surveys conducted on forereef habitats around Guguan during MARAMP 2003, 2005, and 2007. Values of macroalgal cover from towed-diver surveys includes turf algae only in 2003. No REA surveys using the line-point-intercept method were conducted in 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

Macroalgal Genera and Functional Groups

In the field, because of their small size or similarity in appearance, turf algae, crustose coralline red algae, cyanophytes (blue-green algae), and branched, nongeniculate coralline red algae were lumped into functional group categories. The generic names of macroalgae from field observations are tentative, since microscopic analysis is necessary for proper taxonomic identification. The lengthy process of laboratory-based taxonomic identification of all algal species collected at REA sites is about 90% complete for the northern islands of the Mariana Archipelago with hundreds of species identified so far. Ultimately, based on this microscopic analysis, the generic names of macroalgae reported in this section may change and algal diversity reported for each REA site likely will increase.

During MARAMP 2003, REA benthic surveys were conducted at 3 sites on forereef habitats at Guguan. In the field, 9 macroalgal genera (1 red, 1 brown and 7 green), containing at least 9 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed. GUG-03 in the northwest region had the highest macroalgal generic diversity with 6 genera, containing 6 species, documented in the field. The lowest macroalgal generic diversity was found in the southeast and southwest regions at GUG-01 and GUG-02, each with 3 species representing 3 genera recorded.

Species of the calcified, red algal genus *Amphiroa* were the most common component of macroalgal communities at Guguan in 2003, occurring in 27.8% of sampled photoquadrats. However, this overall average is misleading as the distribution of the genus *Amphiroa* was not uniform, occurring in 75% of sampled photoquadrats at GUG-02 in the southwest region but in only 8.3% and 0% of sampled photoquadrats at GUG-03 and GUG-01 in the northwest and southeast regions (Fig. 11.6.1d, top panel). Species of the calcified, green algal genus *Halimeda* were found in 13.9% of sampled photoquadrats overall, and in 16.7% and 25% of sampled photoquadrats at GUG-01 and GUG-03. The brown algal genus *Lobophora* was the only other algal genus recorded at more than 1 site at Guguan, although it was seen in only 8.3% of sampled photoquadrats. Of the 6 remaining macroalgal species tentatively identified in the field, most were observed at only 1 site and in low occurrence, making spatial patterns of distribution difficult to determine for most macroalgae at Guguan.

Turf algae and crustose coralline red algae were both exceptionally common in 2003, occurring in 97.2% and 77.8% of photoquadrats sampled at Guguan (Fig. 11.6.1d, top panel). Turf-algal communities were ubiquitous at all sites with site-specific occurrence values of 91.7%–100%. Crustose coralline red algae, occurring in 66.7%–100% of sampled photoquadrats, were found at all sites and were nearly as abundant as turf algae. Cyanobacteria, less common but still observed at all sites, were found in 38.9% of sampled photoquadrats.

During MARAMP 2005, REA benthic surveys were conducted at 1 site on forereef habitat at Guguan. In the field, 5 macroalgal genera (1 red, 3 green, and 1 brown), containing at least 5 species, as well as 2 additional algal functional groups—turf algae, and crustose coralline red algae—were observed.

Species of the green algal genus *Dictyosphaeria* were the most abundant macroalgae at Guguan in 2005, occurring in 33.3% of sampled photoquadrats. Species of the green algal genera *Caulerpa* and *Rhipidosiphon* were both common and each occurred in 25% of sampled photoquadrats. Species of the brown algal genus *Dictyota* also were notably abundant, occurring in 16.7% of sampled photoquadrats. Turf algae and crustose coralline red algae, both exceptionally common, were observed in 100% and 91.7% of sampled photoquadrats (Fig. 11.6.1d, middle panel).

During MARAMP 2007, REA benthic surveys were conducted at 3 sites on forereef habitats at Guguan. In the field, 14 macroalgal genera (5 red, 7 green, and 2 brown), containing at least 14 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed. Algal diversity at Guguan was similar at all sites. At GUG-03 in the northwest region, 8 genera, containing 8 species, were documented in the field. At GUG-01 and GUG-02, in the southeast and southwest regions, 7 species representing 7 genera were recorded at each site.

The genera *Lobophora* and the calcified, red alga *Jania* were equally abundant at Guguan in 2007 (Fig. 11.6.1d, bottom panel), each occurring in 66.7% of sampled photoquadrats. Interestingly, both genera occurred in 100% of photoquadrats sampled at GUG-03 in the northwest region; however, *Lobophora* was twice as abundant as *Jania* at GUG-01 in the southeast region and, conversely, *Jania* was twice as abundant as *Lobophora* at GUG-02 in the southwest region. Species of the genera *Dictyota* and *Halimeda* were the only other algal species recorded at all 3 sites surveyed at Guguan. A fairly even distribution at Guguan was observed for these 2 genera, which were found in 10% and 56.7% of sampled photoquadrats. The red algal genera *Peyssonnelia* and *Portieria* each occurred in 33.3% of the photoquadrats sampled at GUG-01 and were not observed at other sites. Species of 3 additional genera were recorded only at GUG-02: *Amphiroa*, *Boodlea*, and

Tolypiocladia, occurring in 25%, 8.3%, and 8.3% of photoquadrats sampled at that site. Three more genera were recorded only at GUG-03: *Bryopsis, Tydemania*, and *Ventricaria* (now recognized as a species of *Valonia*), occurring in 16.7%, 16.7%, and 33.3% of sampled photoquadrats.

Turf algae, crustose coralline red algae, and cyanobacteria all were exceptionally common in 2007, occurring in 91.6%, 88.9%, and 55.6% of sampled photoquadrats at Guguan (Fig. 11.6.1d, bottom panel). These 3 functional groups were observed at all sites surveyed. Occurrence values for turf algae and crustose coralline algae were ≥ 83.3% at a given site and for cyanobacteria ranged from 50% to 66.7%.

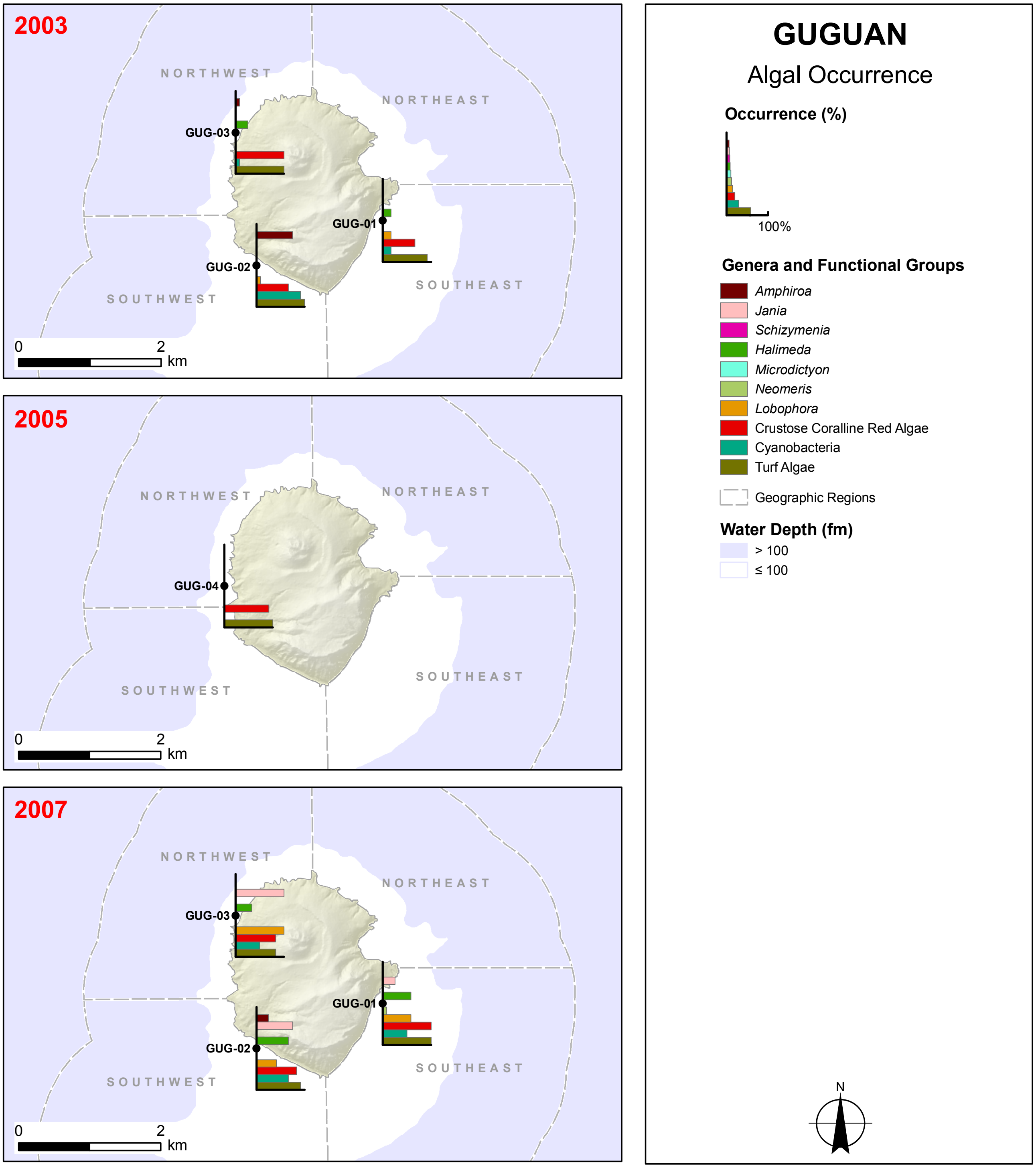
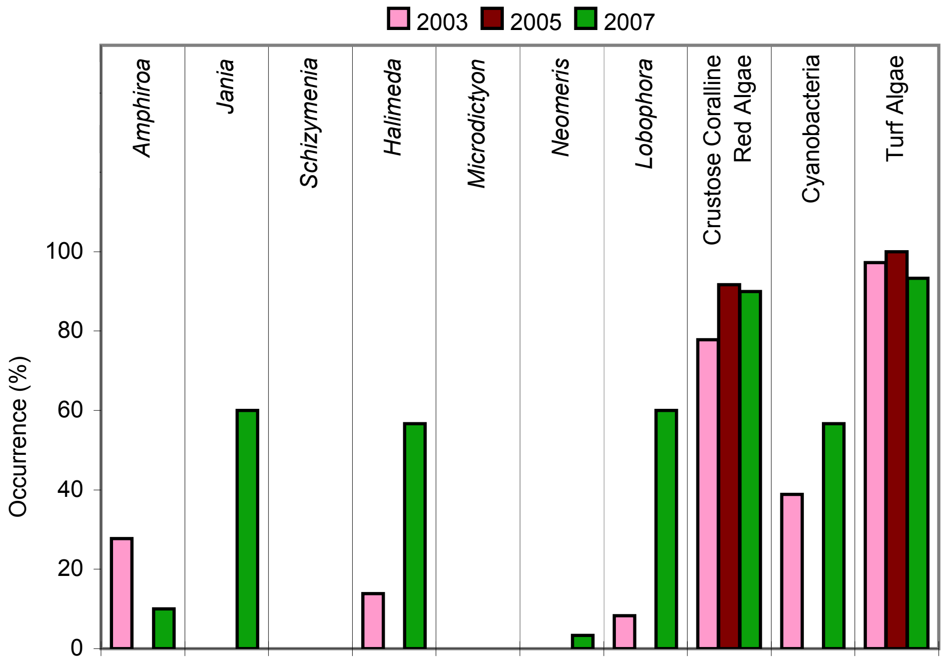


Figure 11.6.1d. Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys of forereef habitats conducted at Guguan during MARAMP 2003, 2005, and 2007. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. The length of the x-axis denotes 100% occurrence.

The number of macroalgal genera recorded on forereef habitats at Guguan increased from 9 during MARAMP 2003 to 15 during MARAMP 2007. Only 6 genera that were present in 2003 were also recorded in 2007, and 8 genera observed in 2007 were not seen in 2003. Similarly, 3 genera that were recorded in 2003 were not observed in 2007. Differences in survey effort and other factors likely can account for this increase in estimated macroalgal diversity (for information on data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”). Only 5 distinct macroalgal genera were recorded in 2005, when only a single site was surveyed at Guguan.

The genera *Halimeda* and *Lobophora* were minor benthic components in 2003 but substantial components in 2007, occurring in 13.9% and 8.3% of photoquadrats sampled at Guguan in 2003 but in 56.7% and 60% of sampled photoquadrats in 2007 (Fig. 11.6.1e). Although *Lobophora* was not recorded at GUG-03 in the northwest region in 2003, this genus was found in every single photoquadrat at this same site in 2007. Similarly, the genus *Jania* was not recorded in 2003 or 2005, but this genus was observed in high abundance in 2007 when compared to results from earlier survey years, with site-specific occurrence values of 25%, 75%, and 100% at the 3 sites surveyed. Genera commonly encountered in low abundance during all survey years included *Bryopsis*, *Caulerpa*, *Dictyosphaeria*, and *Dictyota*. Four additional genera were commonly recorded in low abundance in 2007 only: *Peyssonnelia*, *Portiera, Tydemania*, and *Ventricaria (Valonia*). The genus *Amphiroa* was observed in 27.8% of photoquadrats sampled in 2003 at Guguan but in only 10% of sampled photoquadrats in 2007.

Figure 11.6.1e. Temporal comparison of occurrence (%) values from REA benthic surveys of algal genera and functional groups conducted on forereef habitats at Guguan during MARAMP 2003, 2005 and 2007.



11.6.2 Coralline-algal-disease Surveys

During MARAMP 2007, REA coralline-algal-disease surveys were conducted in concert with coral-disease assessments at 3 sites on forereef habitats at Guguan. These surveys covered a total reef area of ~ 700 m^2 and detected only 1 case of coralline lethal orange disease. Disease was found only at GUG-03 in the northwest region (Fig. 11.6.2a).

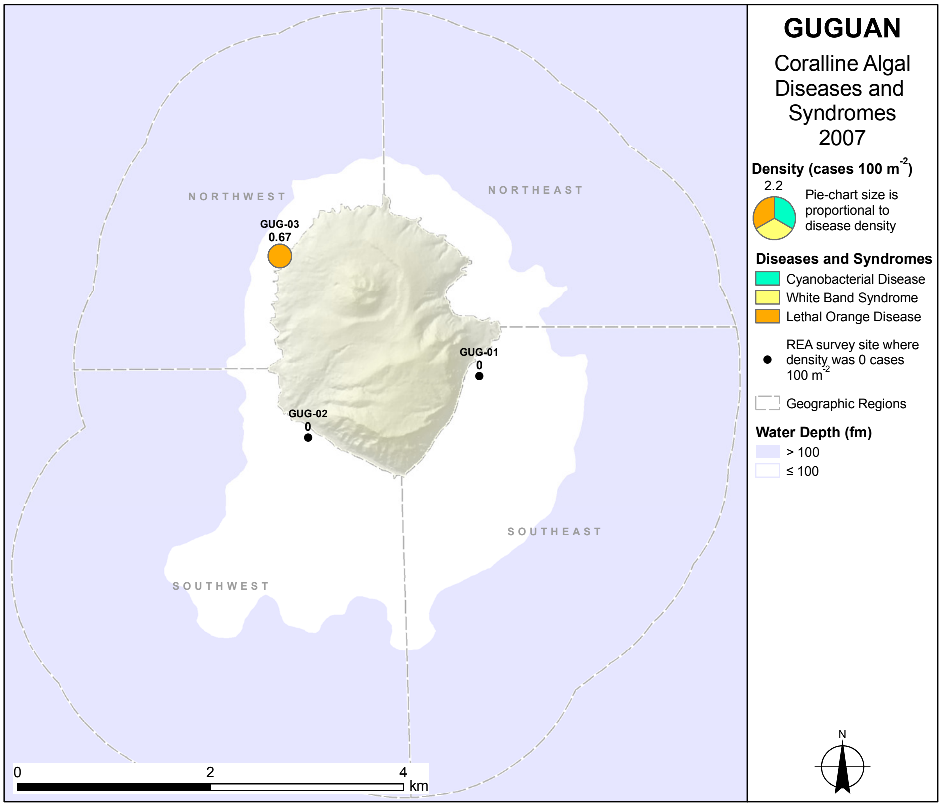


Figure 11.6.2a. Densities (cases 100 m^{-2}) of coralline-algal diseases from REA benthic surveys conducted on forereef habitats at Guguan during MARAMP 2007. The color-coded portions of the pie chart indicate disease-specific density.

11.7 Benthic Macroinvertebrates

11.7.1 Benthic Macroinvertebrates Surveys

Four groups of benthic macroinvertebrates—sea urchins, sea cucumbers, giant clams, and crown-of-thorns seastars (COTS)—were monitored on forereef habitats around the island of Guguan through benthic REA and towed-diver survey methods during MARAMP 2003, 2005, and 2007. This section describes by group the results of these surveys. A list of additional taxa observed during REA invertebrate surveys is provided in Chapter 3: “Archipelagic Comparisons.”

Monitoring these 4 groups of ecologically and economically important taxa provides insight into the population distribution, community structure, and habitats of the coral reef ecosystems of the Mariana Archipelago. High densities of the corallivorous COTS can affect greatly the community structure of reef ecosystems. Giant clams are filter feeders that are sought after in the Indo-Pacific for their meat, which is considered a delicacy, and for their shells. Sea cucumbers, sand-producing detritus foragers, are harvested for food. Sea urchins are important algal grazers and bioeroders.

In 2003, 3 REA surveys and 6 towed-diver benthic surveys were conducted. In 2005, because of weather constraints, only 1 REA survey and 2 towed-diver benthic surveys were conducted on the west coast of Guguan. In 2007, 2 REA surveys and 5 towed-diver benthic surveys were performed around Guguan. When considering survey results from towed-diver surveys, keep in mind that cryptic or small organisms can be difficult for divers to see, so the density values presented in this report, especially of giant clams and sea urchins, may under-represent the number of individuals present.

Overall, both REA and towed-diver surveys suggested low daytime macroinvertebrate abundance on forereef habitats around Guguan compared to the rest of the Mariana Archipelago. Minor fluctuations in observed densities between sampling periods occurred with all target groups. Temporal patterns of islandwide mean macroinvertebrate density on forereef habitats around Guguan—from towed-diver benthic surveys during MARAMP 2003, 2005, and 2007—are shown later in this section (Fig. 11.7.1b, d, f, and h).

Giant Clams

During MARAMP 2003, species of *Tridacna* giant clams were observed at all 3 REA sites surveyed and in 5 of the 6 towed-diver surveys conducted around Guguan (Fig. 11.7.1a, top panel). The sample mean density of giant clams from REA surveys was 8.33 organisms 100 m^{-2} (SE 6.84), and the islandwide mean density from towed-diver surveys was 0.08 organisms 100 m^{-2} (SE 0.01). Survey results suggest giant clams were most abundant at REA site GUG-02 in the southwest region with 22 organism 100 m^{-2}. Among all towed-diver surveys around this island, the survey completed in the

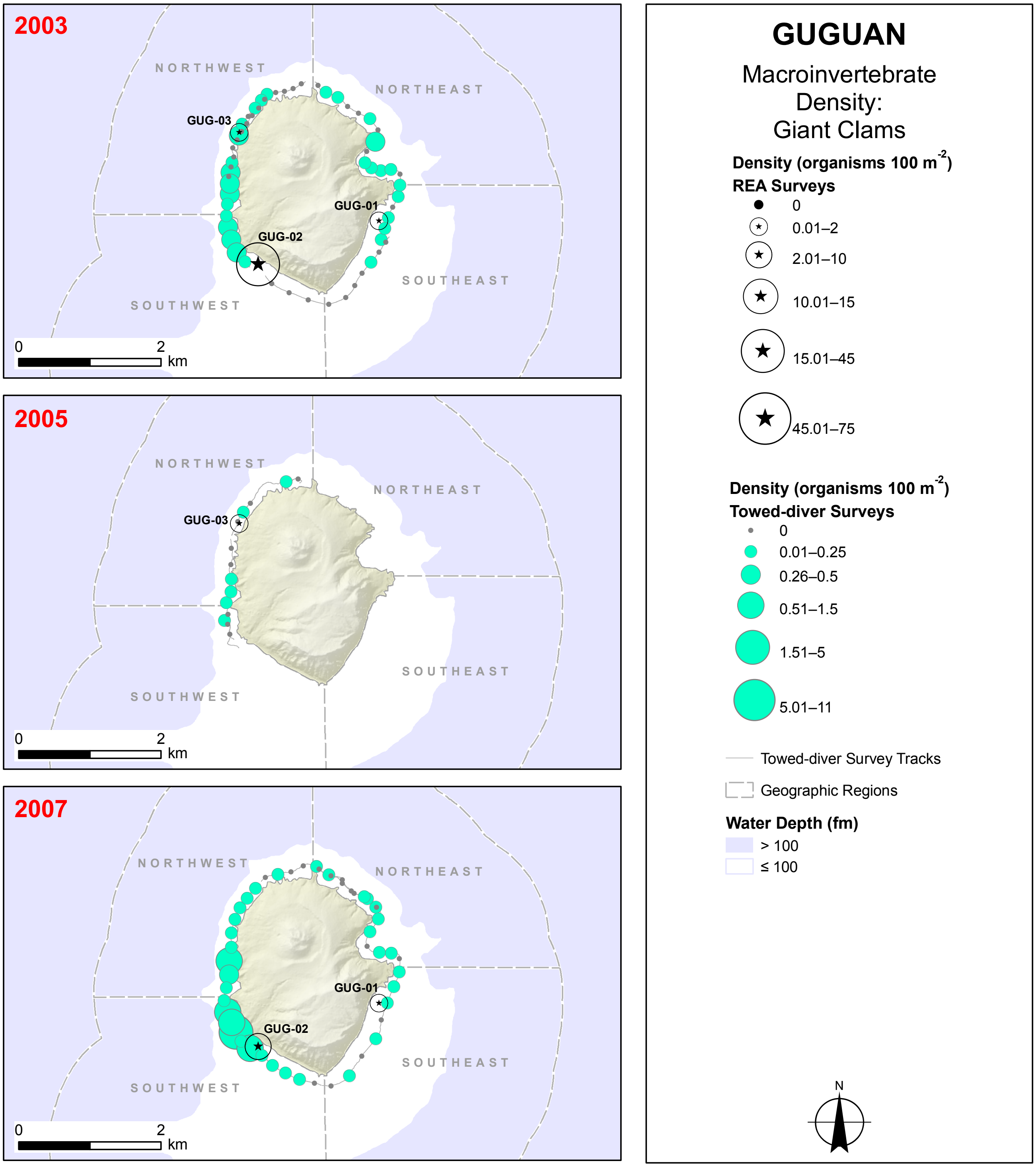


Figure 11.7.1a. Densities (organisms 100 m^{-2}) of giant clams from REA and towed-diver benthic surveys of forereef habitats conducted around Guguan during MARAMP 2003, 2005, and 2007.

southwest region had the highest mean density of giant clams with 0.29 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.48 organisms 100 m^{-2}. The second-greatest mean density of giant clams from towed-diver surveys was 0.06 organisms 100 m^{-2}, recorded along the eastern shore; segment densities ranged from 0 to 0.21 organisms 100 m^{-2}.

During MARAMP 2005, giant clams were observed at the 1 REA site that was surveyed and in all 3 towed-diver surveys conducted on the west coast of Guguan (Fig. 11.7.1a, middle panel). The giant clam density at GUG-03 was 1 organism 100 m^{-2}, and the overall mean density from towed-diver surveys was 0.04 organisms 100 m^{-2} (SE 0.01). Among all towed-diver surveys around this island, the survey completed in the northwest region had the highest mean density with 0.04 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.12 organisms 100 m^{-2}.

During MARAMP 2007, giant clams were observed at both of the REA sites surveyed and in all 5 towed-diver surveys conducted around Guguan (Fig. 11.7.1a, bottom panel). The sample mean density of giant clams from the 2 REA surveys was 1.67 organisms 100 m^{-2} (SE 1.33), and the islandwide mean density from towed-diver surveys was 0.16 organisms 100 m^{-2} (SE 0.05). Survey results suggest giant clams were most abundant at GUG-02 in the southwest region with 3 organisms 100 m^{-2}. Among all towed-diver surveys around this island, the survey completed in the southwest region had the highest mean density of giant clams with 0.5 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 2.47 organisms 100 m^{-2}. The towed-diver survey along the western shore had the second-greatest mean density with 0.16 organisms 100 m^{-2}; segment densities for this survey ranged from 0.47 to 0.69 organisms 100 m^{-2}.

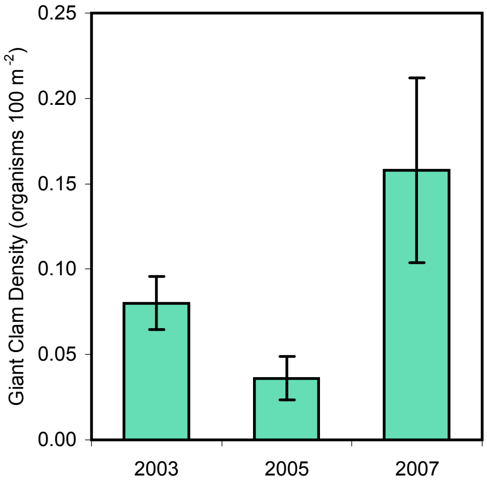


Figure 11.7.1b. Temporal comparison of mean densities (organisms 100 m^{-2}) of giant clams from towed-diver benthic surveys conducted on forereef habitats around Guguan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

During MARAMP 2003 and 2007, the highest densities of giant clams from towed-diver surveys were recorded along the west coast of Guguan. The overall observed mean density of giant clams at Guguan was higher in 2003 and 2007 than in 2005 (Fig. 11.7.1b). Minor fluctuations in density are not necessarily indicative of changes in the population structure of giant clams (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

Crown-of-thorns Seastars

During MARAMP 2003, no crown-of-thorns seastars (*Acanthaster planci*) were observed at the 3 REA sites surveyed at Guguan, and just 1 of the 6 towed-diver surveys had recordings of COTS (Fig. 11.7.1c, top panel). This towed-diver survey was completed along the eastern shore and had a mean COTS density of 0.001 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.06 organisms 100 m^{-2}.

During MARAMP 2005, no COTS were observed at the 1 REA site surveyed at Guguan, but both towed-diver surveys had recordings of COTS with an overall mean density of 0.04 organisms 100 m^{-2} (Fig. 11.7.1c, middle panel). The towed-diver survey conducted in the northwest region had the highest mean COTS density with 0.07 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.25 organisms 100 m^{-2}.

During MARAMP 2007, no COTS were observed at the 2 REA sites surveyed or in the 5 towed-diver surveys conducted around Guguan (Fig. 11.7.1c, bottom panel).

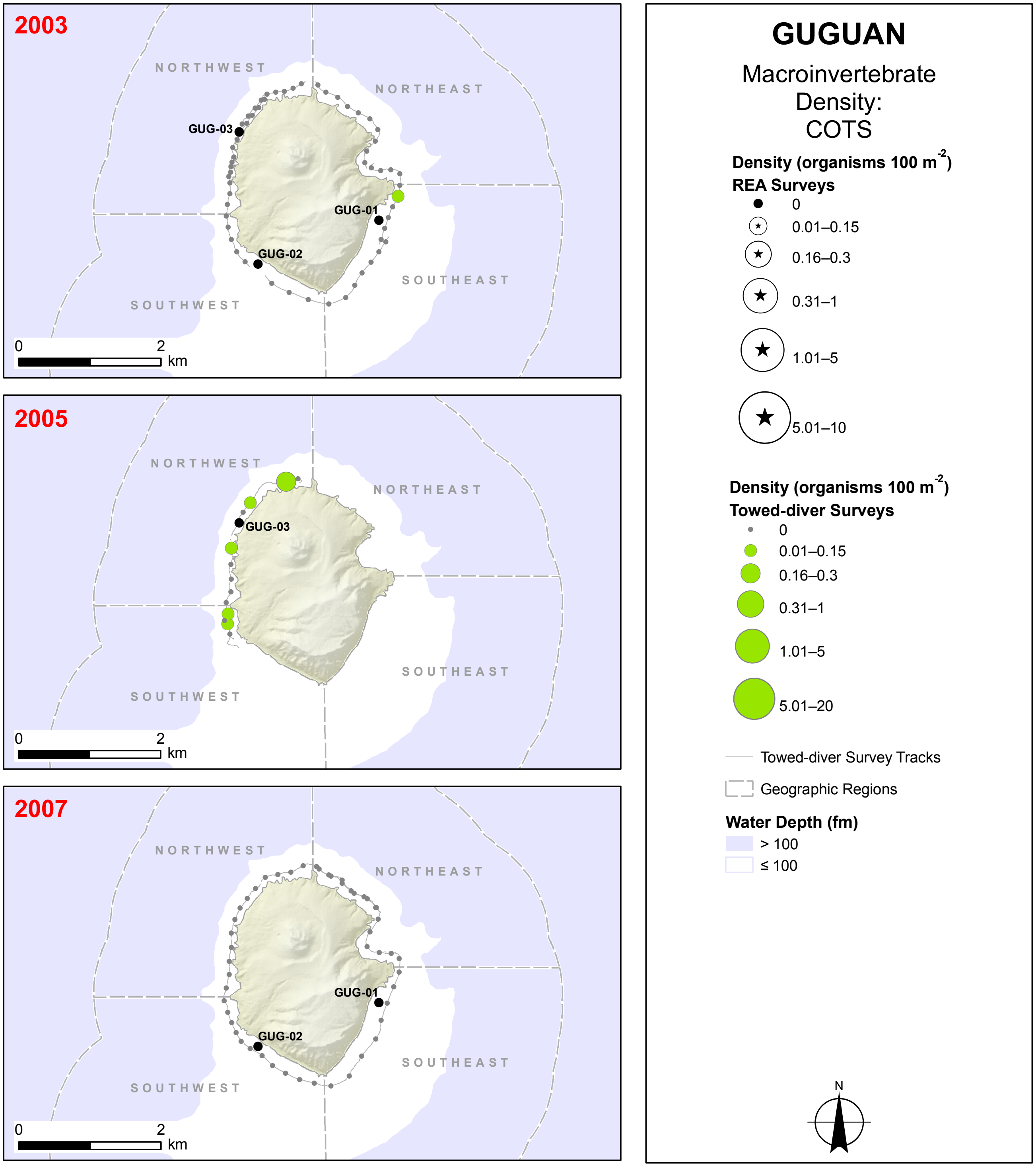


Figure 11.7.1c. Densities (organisms 100 m^{-2}) of COTS from REA and towed-diver benthic surveys of forereef habitats conducted around Guguan during MARAMP 2003, 2005, and 2007.

During the 3 MARAMP survey years, few observations of COTS were made during towed-diver benthic surveys conducted around Guguan (Fig. 11.7.1d). Despite the limited number of towed-diver surveys conducted in 2005, COTS densities were greater in 2005 than in 2003 and 2007. This variation in COTS density is not necessarily indicative of changes in the population structure of COTS (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys"). COTS density naturally fluctuates with food availability and successful recruitment events (Birkeland and Lucas 1990; Fabricius et al. 2010; and Yamaguchi 1987).

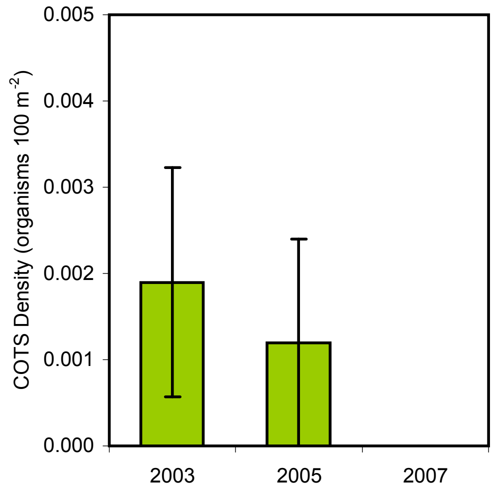


Figure 11.7.1d. Temporal comparison of COTS mean densities (organisms 100 m^{-2}) from towed-diver benthic surveys conducted on forereef habitats around Guguan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Sea Cucumbers

During MARAMP 2003, no sea cucumbers were observed at the 3 REA sites surveyed at Guguan, but 5 of the 6 towed-diver surveys had recordings of sea cucumbers (Fig. 11.7.1e, top panel) with an islandwide mean density of 0.04 organisms 100 m^{-2} (SE 0.01). Among all towed-diver surveys around this island, the survey completed in the southwest region had the highest mean density of sea cucumbers with 0.12 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.55 organisms 100 m^{-2}. The second-greatest mean density of sea cucumbers from a towed-diver survey was 0.03 organisms 100 m^{-2}, recorded in the northeast region; segment densities ranged from 0 to 0.58 organisms 100 m^{-2}.

During MARAMP 2005, no sea cucumbers were observed at the 1 REA site surveyed at Guguan, and only 1 of the 2 towed-diver surveys conducted had recordings of sea cucumbers (Fig. 11.7.1e, middle panel). The mean density of sea cucumbers from this survey was 0.01 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.07 organisms 100 m^{-2}.

During MARAMP 2007, sea cucumbers were observed at 1 of the 2 REA sites surveyed and in all 5 towed-diver surveys conducted around Guguan (Fig. 11.7.1e, bottom panel). GUG-01 had a density of sea cucumbers of 0.33 organisms 100 m^{-2}, which consisted entirely of species of the genus *Actinopyga.* The islandwide mean density of sea cucumbers from towed-diver surveys was 0.06 organisms 100 m^{-2} (SE 0.01). Among all towed-diver surveys around this island, the survey completed along the western shoreline had the highest mean density of sea cucumbers with 0.17 organisms 100 m^{-2}; segment densities ranged from 0 to 0.58 organisms 100 m^{-2}.

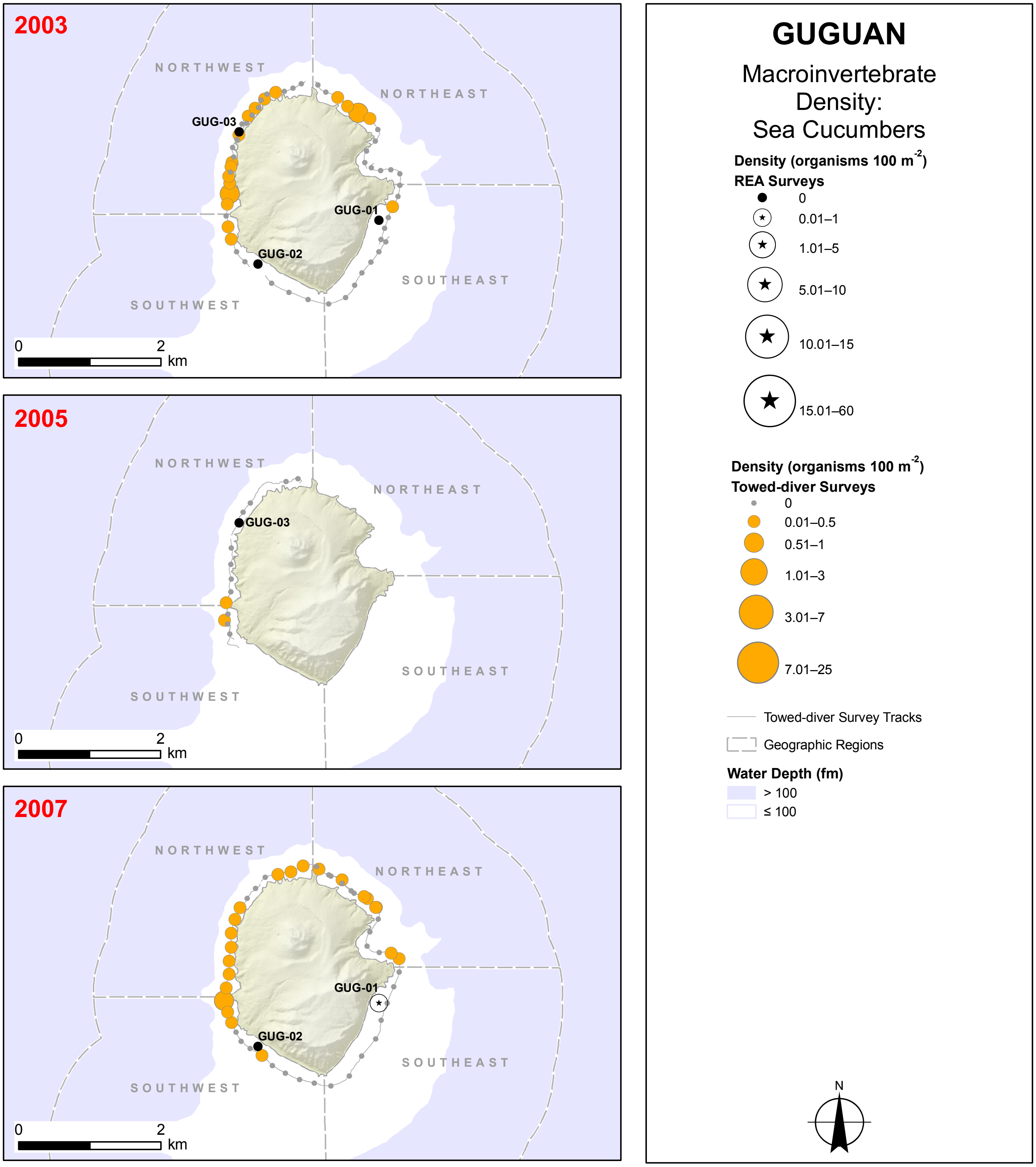


Figure 11.7.1e. Densities (organisms 100 m^{-2}) of sea cucumbers from REA and towed-diver benthic surveys of forereef habitats conducted around Guguan during MARAMP 2003, 2005, and 2007.

Towed-diver surveys suggested low daytime abundance of sea cucumbers around Guguan during MARAMP 2003, 2005, and 2007, relative to the rest of the Mariana Archipelago (Fig. 11.7.1f). Fluctuations in observed densities are not necessarily indicative of changes in the population structure of sea cucumbers (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

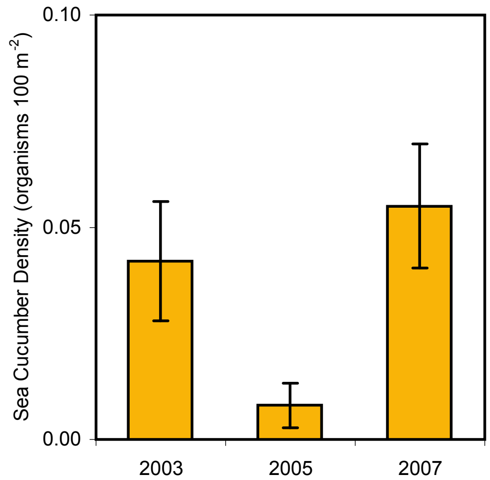


Figure 11.7.1f. Temporal comparison of mean densities (organisms 100 m^{-2}) of sea cucumbers from towed-diver benthic surveys conducted on forereef habitats around Guguan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean

Sea Urchins

During MARAMP 2003, sea urchins were observed at all 3 REA sites surveyed and in 4 of the 6 towed-diver surveys conducted around Guguan (Fig. 11.7.1g, top panel). The sample mean density for REA surveys was 68 organisms 100 m^{-2} (SE 15.39), and the islandwide mean density of sea urchins from towed-diver surveys was 0.08 organisms 100 m^{-2} (SE 0.04). Survey results suggest that sea cucumbers were most abundant at GUG-02 in the southwest region with a mean density of sea urchins of 98 organisms 100 m^{-2}, and 96% of the species of sea urchins recorded at this site were rock-boring urchins from the genus *Echinostrephus*. Other genera observed at GUG-02 were *Echinometra* and *Echinothrix.* GUG-03 had the second-greatest density with 59 organisms 100 m^{-2}; of the sea urchin species recorded at this site, 69% were of the genus *Diadema,* and the remaining species were of the genus *Echinothrix.*

Among all towed-diver surveys conducted around Guguan in 2003, the survey completed around the eastern point of this island had the highest mean density of sea urchins at 0.38 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 2.34 organisms 100 m^{-2}. The second-greatest mean density of sea urchins from a towed-diver survey was 0.06 organisms 100 m^{-2}, recorded along the center of the west coast; segment densities ranged from 0 to 0.35 organisms 100 m^{-2}.

During MARAMP 2005, no sea urchins were observed at the 1 REA site surveyed or in the 3 towed-diver surveys conducted along the west coast of Guguan (Fig. 11.7.1g, bottom panel).

During MARAMP 2007, sea urchins were observed at both REA sites surveyed and in all 5 towed-diver surveys conducted around Guguan (Fig. 11.7.1g, bottom panel). The sample mean density from REA surveys was 8.67 organisms 100 m^{-2} (SE 3.33), and the islandwide mean density of sea urchins from towed-diver surveys was 2.71 organisms 100 m^{-2} (SE 0.72). GUG-01 had the highest density of sea urchins with 12 organisms 100 m^{-2}, which consisted entirely of species of the genus *Echinostrephus*.

Among all towed-diver surveys conducted around Guguan in 2007, the survey completed in the southeast region had the highest mean density of sea urchins at 8.66 organisms 100 m^{-2}; segment densities from this survey ranged from 0.49 to 23.05 organisms 100 m^{-2}. The second-greatest mean density from a towed-diver survey was 2.48 organisms 100 m^{-2}, recorded along the northern shoreline; segment densities ranged from 0 to 16.98 organisms 100 m^{-2}.

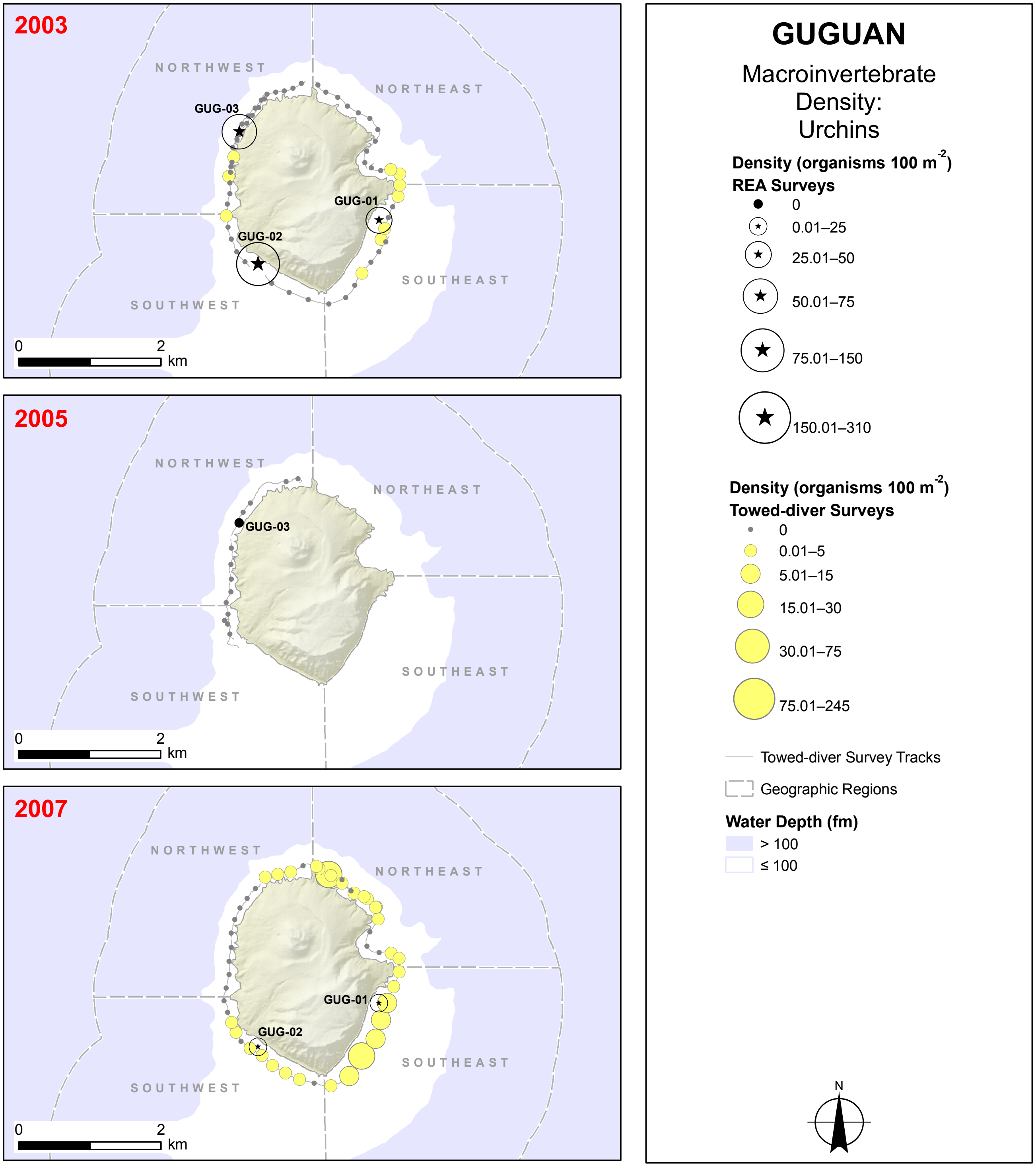


Figure 11.7.1g. Densities (organisms 100 m^{-2}) of sea urchins from REA and towed-diver benthic surveys of forereef habitats conducted around Guguan during MARAMP 2003, 2005, and 2007.

Towed-diver surveys suggested low daytime abundance of sea urchins around Guguan during MARAMP 2003, 2005, and 2007, compared to the rest of the Mariana Archipelago, with density values higher in 2007 than in 2003 (Fig. 11.7.1h). Fluctuations in densities between MARAMP years are not necessarily indicative of changes in the population structure of sea urchins (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

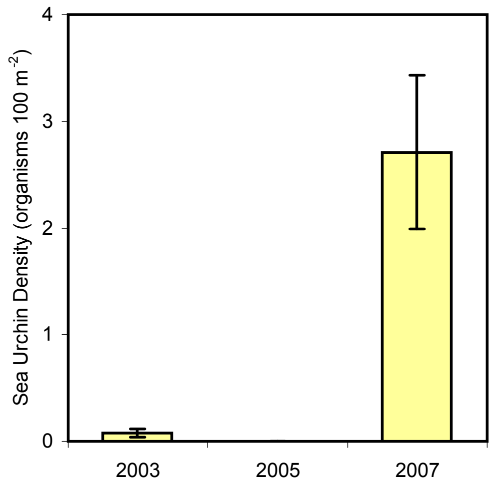


Figure 11.7.1h. Temporal comparison of mean densities (organisms 100 m^{-2}) of sea urchins from towed-diver benthic surveys conducted on forereef habitats around Guguan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

11.8 Reef Fishes

11.8.1 Reef Fish Surveys

Large-fish Biomass

During MARAMP 2003, 6 towed-diver surveys for large fishes (≥ 50 cm in total length [TL]) were conducted in forereef habitats around the island of Guguan. The overall estimated mean biomass of large fishes, calculated as weight per unit area, was 0. 56 kg 100 m^{-2} (SE 0.12), a low value compared to other survey areas in the Mariana Archipelago. Biomass values for large fishes were highest in the northwest region, where reef sharks (Carcharhinidae), nurse sharks (Ginglymostomatidae), and snappers (Lutjanidae) were common (Fig. 11.8.1a, top panel). Snappers and sharks together accounted for the greatest proportion (68%) or 0.38 kg 100 m^{-2} of islandwide mean large-fish biomass. Snappers alone contributed 45% of overall mean biomass of large fishes, and the twinspot snapper (*Lutjanus bohar*) and the black and white snapper (*Macolor niger*) were the dominant snapper species by biomass, accounting for 0.15 kg 100 m^{-2} and 0.07 kg 100 m^{-2} of islandwide mean large-fish biomass. The whitetip reef shark (*Triaenodon obesus*) was the major shark species in terms of biomass, contributing 0.07 kg 100 m^{-2} of overall mean large-fish biomass. During this survey period, 8 sharks were observed: 6 whitetip reef sharks, 1 grey reef shark (*Carcharhinus amblyrhynchos*), and 1 tawny nurse shark (*Nebrius ferrugineus*).

During MARAMP 2005, 3 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats at Guguan. Because of weather constraints, surveys were limited to the west side of this island. The overall mean biomass of large fishes was 0.61 kg 100 m^{-2} (SE 0.31), a value similar to the biomass recorded in 2003. Biomass values for large fishes were highest along the center of the west coast, where sharks contributed a majority of overall mean large-fish biomass (Fig. 11.8.1a, middle panel). Nurse sharks and reef sharks contributed 65% of overall mean biomass of large fishes. The tawny nurse shark alone contributed 50% of overall large-fish biomass. During this survey period, 6 sharks were observed: 3 grey reef sharks, 2 whitetip reef sharks, and 1 large (225 cm in TL) tawny nurse shark. Jacks (Carangidae) composed the family with the second-highest biomass, contributing 9% of overall large-fish biomass.

During MARAMP 2007, 5 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats around Guguan. The overall mean biomass of large fishes was 0.31 kg 100 m^{-2} (SE 0.12), lower than estimates made in 2003 and 2005. Biomass values for large fishes were distributed fairly evenly around this island; however, they were highest in the southern end of the northeast region where sharks and snappers were common (Fig. 11.8.1a, bottom panel). Reef sharks and snappers together accounted for the greatest proportion (69%) or 0.21 kg 100 m^{-2} of the overall mean biomass of large fishes. The grey reef shark was the shark species with the highest biomass, contributing 0.05 kg 100 m^{-2} of overall large-fish biomass. Parrotfishes (Scaridae) also were commonly observed and accounted for 14% of overall large-fish biomass, and the redlip parrotfish (*Scarus rubroviolaceus*) was the major biomass contributor. During this survey period, 11 sharks were observed: 6 whitetip reef sharks, 4 grey reef sharks, and 1 blacktip reef shark (*Carcharhinus melanopterus*).

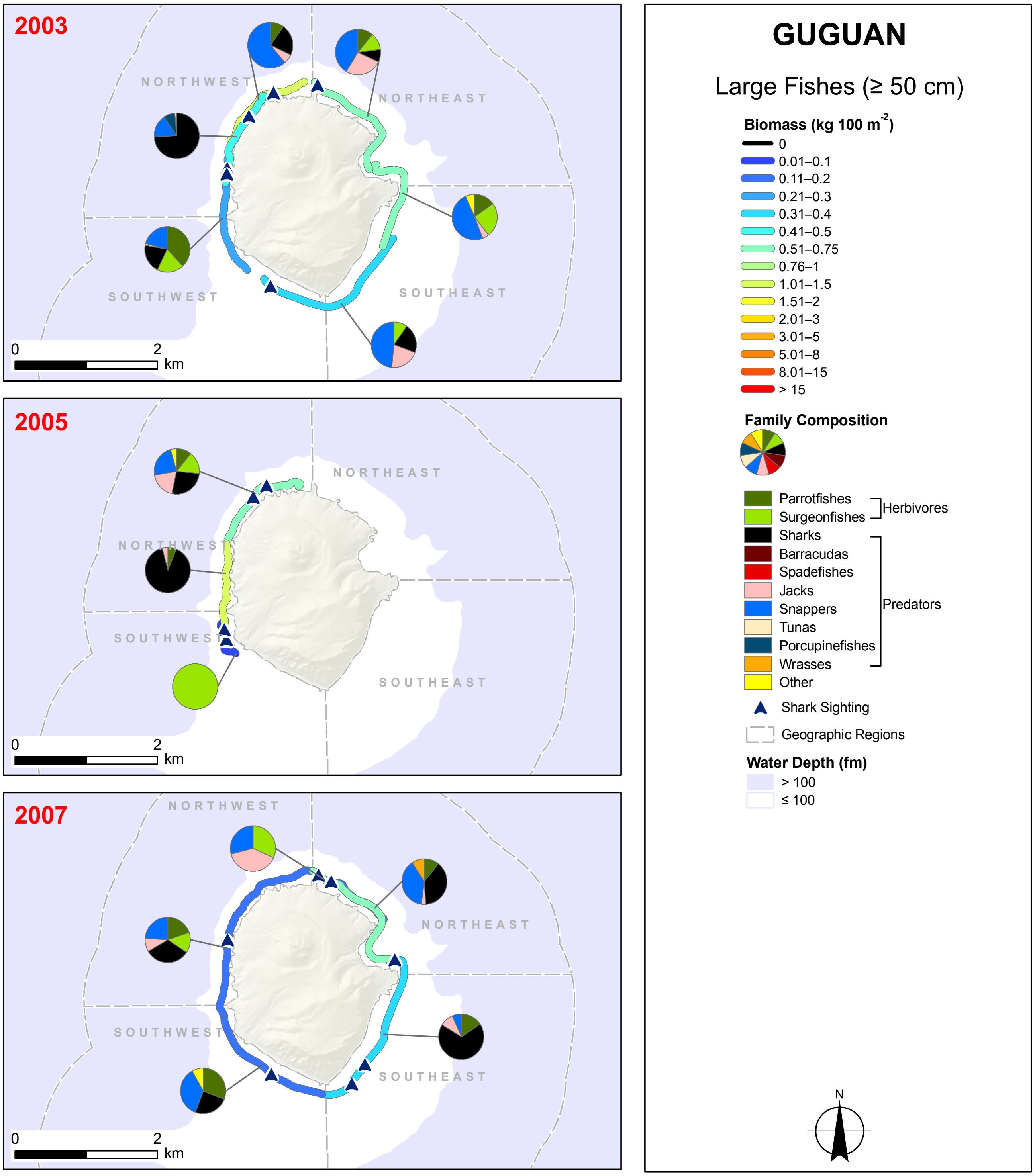


Figure 11.8.1a. Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}), family composition, and shark sightings from towed-diver fish surveys of forereef habitats conducted around Guguan during MARAMP 2003, 2005, and 2007. Each blue triangle represents a sighting of one or more sharks recorded inside or outside the survey area over which it is shown.

Overall mean biomass of large fishes from towed-diver surveys of forereef habitats was moderate for the 3 MARAMP survey years, compared to results from other islands of the Mariana Archipelago. Large-fish biomass values were slightly lower in 2007, with an overall mean of 0.31 kg 100 m^{-2} (SE 0.12), than in 2003 (Fig. 11.8.1b) with an overall mean of 0.56 kg 100 m^{-2} (SE 0.12). Sharks consistently contributed large proportions to overall large-fish biomass during the 3 MARAMP survey periods. Snappers were common during surveys conducted in 2003 and 2007, and the twinspot snapper and the black and white snapper were the species that contributed the greatest proportion of snapper biomass. Notable

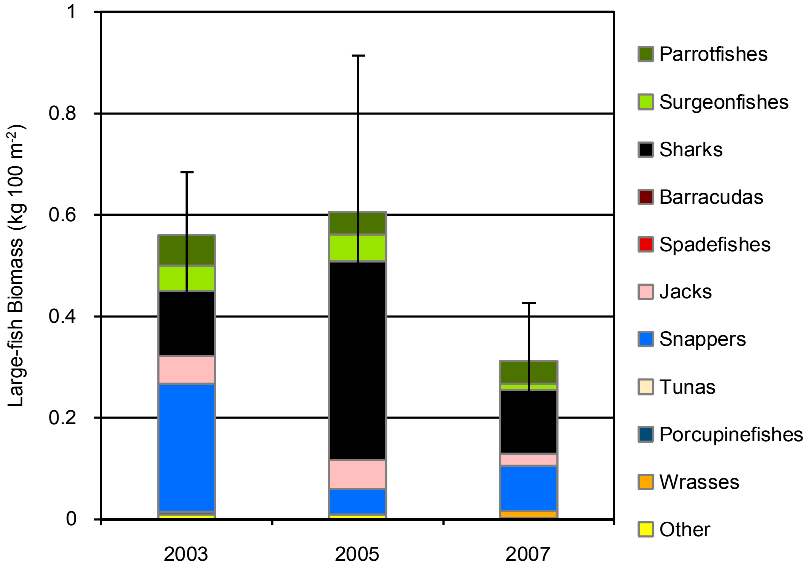


Figure 11.8.1b. Temporal comparison of mean values of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}) from towed-diver fish surveys of forereef habitats conducted around Guguan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

observations around Guguan included a single sighting of the humphead wrasse (*Cheilinus undulatus*) in 2007 and sightings of giant trevally (*Caranx ignobilis*) in 2005 and 2007.

Total Fish Biomass and Species Richness

Total fish biomass for the 3 REA sites surveyed at Guguan during MARAMP 2003 was high, compared to other sites in the Mariana Archipelago, with an overall sample mean of 16.72 kg 100 m^{-2} (SE 1.43). The highest biomass of 19.18 kg 100 m^{-2} was observed in the southwest region at GUG-02, where 2 whitetip reef sharks were recorded (Fig. 11.8.1c, top panel). Surgeonfishes accounted for the largest proportion (24%) or 3.86 kg 100 m^{-2} of total fish biomass at Guguan. The whitecheek surgeonfish (*Acanthurus nigricans*) was the dominant surgeonfish species by biomass, contributing 29% of surgeonfish biomass. The whitetip reef shark was the only shark species observed in 2003, accounting for 2.34 kg 100 m^{-2} of total fish biomass.

Based on REA surveys conducted during MARAMP 2003, species richness at Guguan was fairly consistent among the 3 sites surveyed with a range of 46–53 species 100 m^{-2}. The highest diversity was observed at GUG-03 in the northwest region (Fig. 11.8.1c, top panel). Wrasses (Labridae) and surgeonfishes composed the 2 most represented families with 18 and 15 species recorded. The ornate wrasse (*Halichoeres ornatissimus*) was the most abundant wrasse species, while the orangespine unicornfish (*Naso lituratus*) was the most abundant surgeonfish species. A recent large recruitment of the orangespine surgeonfish contributed to its dominance of counts with more than 150 individuals 100 m^{-2} observed. Damselfishes (Pomacentridae) also were abundant, and Vanderbilt's chromis (*Chromis vanderbilti*) was the most common damselfish with 41 individuals 100 m^{-2} recorded.

Total fish biomass for the 2 REA sites surveyed in forereef habitats at Guguan during MARAMP 2005 was high, compared to other sites in the Mariana Archipelago, with a sample mean of 18.18 kg 100 m^{-2} (SE 1.33). The highest biomass of 19.51 kg 100 m^{-2} was observed in the northwest region at GUG-03 (Fig. 11.8.1c, middle panel). Surgeonfishes accounted for the largest proportion (45%) or 8.16 kg 100 m^{-2} of the total fish biomass. The whitecheek surgeonfish and striated surgeonfish (*Ctenochaetus striatus*) were the 2 main surgeonfish species by biomass, contributing 38% and 24% of surgeonfish biomass. During this survey period, 2 sharks were observed: 1 whitetip reef shark and 1 tawny nurse shark.

Based on REA surveys conducted during MARAMP 2005, species richness at Guguan was moderate at both surveyed sites with 37 and 39 species 100 m^{-2} (Fig. 11.8.1c, bottom panel). Similar to observations made in 2003, wrasses and surgeonfishes composed the 2 most represented families with 19 and 15 species recorded. The ornate wrasse was the most abundant wrasse species with 7 individuals 100 m^{-2} observed, and the whitebar surgeonfish (*Acanthurus leucopareius*) was the most abundant surgeonfish species with 22 individuals 100 m^{-2} recorded. Damselfishes dominated counts and made up the most abundant taxon overall, and the midget chromis (*Chromis acares*) was the most abundant damselfish species with 57 individuals 100 m^{-2} recorded.

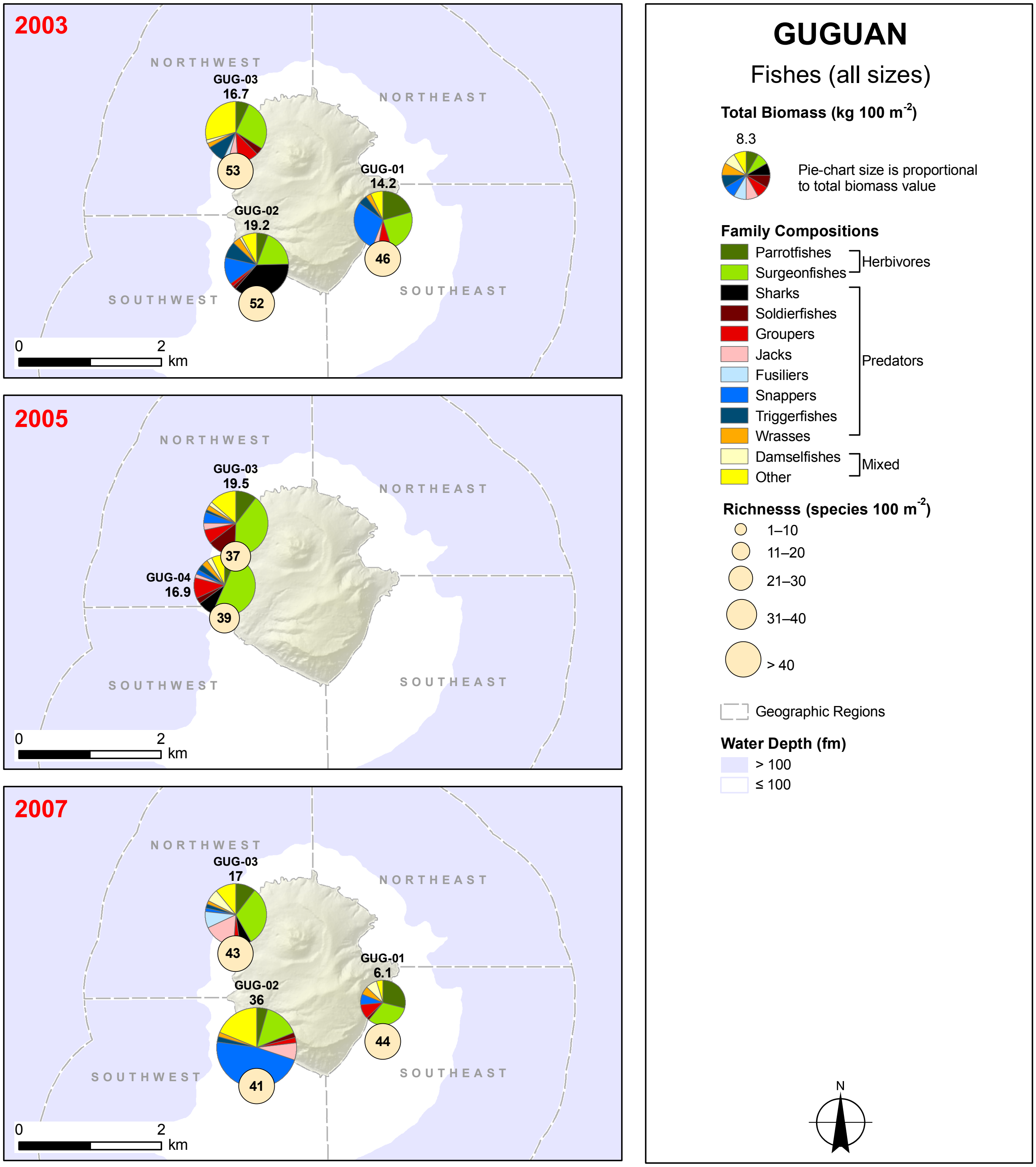


Figure 11.8.1c. Observations of total fish biomass (all species and size classes in kg 100 m^{-2}), family composition, and species richness (species 100 m^{-2}) from REA fish surveys using the belt-transect method in forereef habitats at Guguan during MARAMP 2003, 2005, and 2007.

Total fish biomass for the 3 REA sites surveyed in forereef habitats at Guguan during MARAMP 2007 was high, compared to other sites in the Mariana Archipelago, with an overall sample mean of 19.70 kg 100 m^{-2} (SE 8.73). The highest biomass of 35.98 kg 100 m^{-2} was observed in the southwest region at GUG-02, where snappers were common (Fig. 11.8.1c, bottom panel). Snappers and surgeonfishes accounted for 30% and 21% of total fish biomass. The twinspot snapper was the major snapper species by biomass at 4.94 kg 100 m^{-2}. The whitecheek surgeonfish was the dominant surgeonfish species by biomass, accounting for 32% to the total surgeonfish biomass.

Based on REA surveys conducted during MARAMP 2007, species richness at Guguan was moderate and consistent among the 3 sites surveyed with a range of 41–44 species 100 m^{-2}. Similar to observations made in 2003 and 2005, wrasses and surgeonfishes composed the 2 most represented families with 23 and 15 species recorded. The ornate wrasse was the most abundant wrasse species, while the whitecheek surgeonfish was the most abundant surgeonfish species. Damselfishes again composed the most abundant taxon overall, and the midget chromis dominated counts with 240 individuals 100 m^{-2} observed.

No persistent spatial patterns were observed for total fish biomass at Guguan during the 3 MARAMP survey periods. However, GUG-02 in the southwest region had the highest mean total fish biomass for surveys conducted in 2003 and 2007 (this site was not surveyed in 2005 because of weather constraints). Compared to estimates made for the rest of the Mariana Archipelago, overall estimates of total fish biomass for Guguan were among the highest levels found. Total fish biomass was consistent between MARAMP survey years (Fig. 11.8.1d) with an overall sample mean of 18.20 kg 100 m^{-2} (SE 0.86) across the 3 survey periods. Surgeonfishes were abundant and accounted for large portions of total fish biomass in each survey year. The orangespine unicornfish, the whitecheek surgeonfish, and the striated surgeonfish contributed the largest proportions of surgeonfish biomass.

Guguan had the highest overall levels of species richness found in the Mariana Archipelago, with a range of 37–53 species 100 m^{-2} over the 3 MARAMP survey years. No clear, consistent spatial patterns were observed for species richness. Wrasses and surgeonfishes composed the 2 most represented families with an average of 21 and 15 species recorded. Damselfishes were abundant, and the midget chromis and Vanderbilt's chromis dominated damselfish counts.

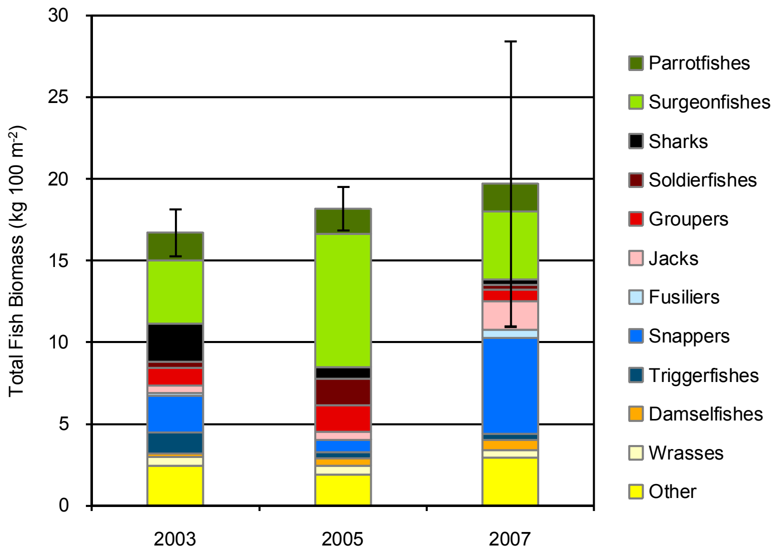


Figure 11.8.1d. Temporal comparison of mean values of total fish biomass (all species and size classes in kg 100 m^{-2}) from REA fish surveys of forereef habitats conducted at Guguan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

11.9 Marine Debris

11.9.1 Marine Debris Surveys

During MARAMP 2003, 2005, and 2007, no marine debris was recorded in the towed-diver surveys of forereef habitats conducted around Guguan.

11.10 Ecosystem Integration

The spatial distributions and temporal patterns of individual coral reef ecosystem components around the island of Guguan are discussed in the discipline-specific sections of this chapter. In this section, key ecological and environmental aspects are considered concurrently to identify potential relationships between various ecosystem components. In addition to this island-level analysis, evaluations across the entire Mariana Archipelago are presented in Chapter 3: "Archipelagic Comparison," including archipelago-wide reef condition indices with ranks for Guguan as well as the other 13 islands covered in this report.

Located in the center of the Mariana Arc, Guguan is characterized by a low elevation and less steep slopes, relative to the topography seen at its neighbor islands. This island consists of 2 volcanoes, with a plain that gently slopes down to the shoreline, except in the south where steep, unstable cliffs are found. The topography created by the presence of the 2 volcanoes naturally delineates the northern and southern submarine seascapes (see Figure 11.3.1b in Section 11.3.1: "Acoustic Mapping"), as well as all that lies between them (Fig. 11.10a).

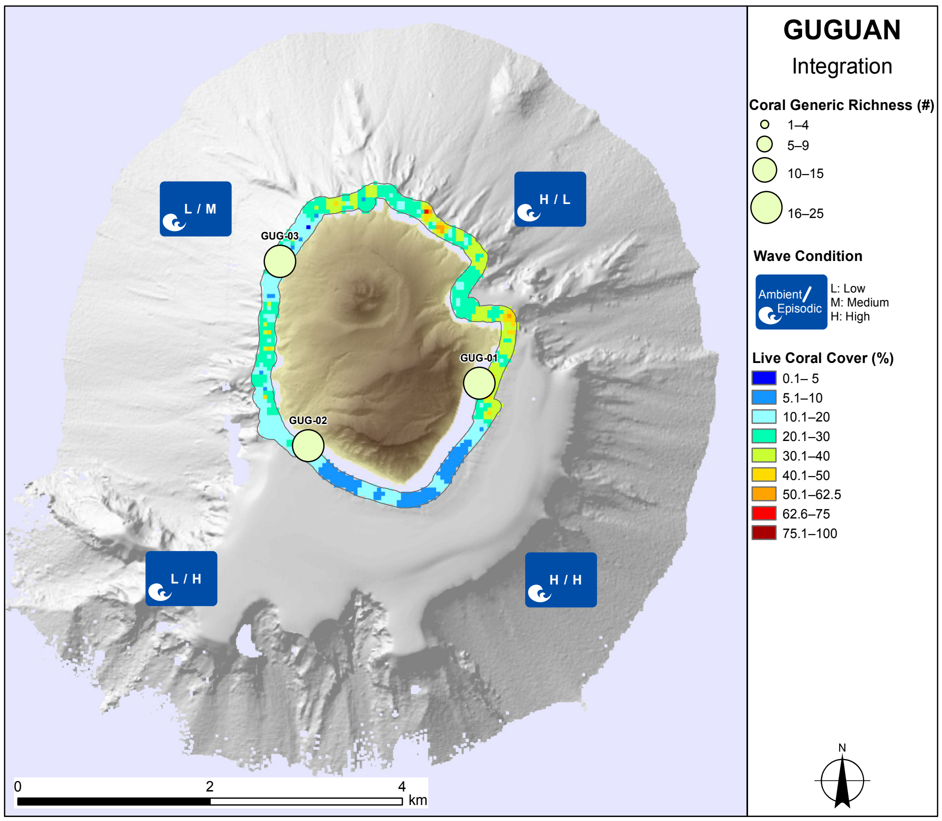


Figure 11.10a. Cover (%) observations of live hard corals from towed-diver surveys and generic richness from REA surveys conducted on forereef habitats around Guguan during MARAMP 2003, 2005, and 2007. Values of coral cover represent interpolated values from the 3 survey years, and values of coral generic richness represent averages of data from the 3 survey years. A large, blue icon indicates the level of ambient and episodic wave exposure for each geographic region. Underlying these data in grey scale is the hillshade bathymetry.

The area north of Guguan is marked by steep submarine slopes (see Figure 11.3.1c in Section 11.3.1: "Acoustic Mapping") with hard substrate of moderate to high complexity (see Figure 11.3.3a in Section 11.3.3: "Habitat Characterization"). The habitat there has a mixture of pavement and spur-and-groove reef with patches of boulders strewn throughout. This area generally supported the highest cover estimates from towed-divers surveys for live hard corals and crustose coralline red algae of all areas surveyed around Guguan, and REA site GUG-03, in the northwest region, had the highest macroalgal diversity recorded during REA surveys across the 3 MARAMP survey years (Fig. 11.10a).

The seascape to the east of Guguan changed drastically from the north to the south. The northeast region was characterized as high-relief, spur-and-groove reef with sections of nearly vertical walls and overall high complexity (see Figure 11.3.3a in Section 11.3.3: "Habitat Characterization"). During a towed-diver survey exiting the eastern-facing bay and heading south, habitat was characterized as continuous reef of medium complexity and farther south transitioned to boulders and sand (Fig. 11.3.3a). Towed-diver surveys conducted on the eastern reefs of Guguan reported high values (up to 50%) of live coral cover in 2003 and moderate values in 2007 (see Figure 11.5.1a in Section 11.5.1: "Coral Surveys"). Furthermore, among all REA sites surveyed in 2007, GUG-01 had the highest levels of coral cover, density, and generic richness (Figs. 11.5.1b and e).

Figure 11.10b. Reef habitat off northern Guguan. *NOAA photo by Robert Schroeder*

South of Guguan, 2 submarine terraces extend ~ 2 km out from the shoreline (see Figure 11.3.1b in Section 11.3.1: "Acoustic Mapping"). A shallow shelf at depths of 25–50 m gives way to a deeper shelf that slopes to depths of 80–130 m. These shelves are fringed by the steepest sloping bathymetry surrounding Guguan, with slopes > 50° (Fig. 11.3.1c). The terraces were characterized as predominantly large sand flats with sections of patch reef and boulders, and towed-diver surveys conducted there generally reported the lowest cover values for live hard corals and crustose coralline red algae, compared to survey results from other areas surveyed at Guguan.

Habitat west of Guguan was characterized as spur-and-groove reef of medium-high complexity (see Figure 11.3.3a in Section 11.3.3: "Habitat Characterization") with the occurrence of vertical walls increasingly common toward the northwest. Compared to other survey areas at Guguan, western reefs supported high values of live coral cover (up to 62.5%) recorded

Figure 11.10c. Reef habitat off northern Guguan. *NOAA photo by Robert Schroeder*

during towed-diver surveys conducted in 2003, but coral cover there was lower in subsequent years (see Figure 11.5.1a in Section 11.5.1: “Coral Surveys”). The highest densities of giant clams at Guguan in 2003 and 2007 were found in the southwest region during towed-diver and REA surveys (Fig. 11.10c; also see Figure 11.7.1a in Section 11.7.1: Benthic Macroinvertebrate Surveys”).

Fish biomass was moderately high at Guguan in comparison to the levels observed at other islands of the Mariana Archipelago. Relative to other northern islands, overall mean biomass of large fishes (≥ 50 cm in TL) was low for the 3 MARAMP survey years, although sharks were observed during each survey period (see Figure 11.8.1b in Section 11.8.1: “Reef Fish Surveys”). In contrast, total fish biomass at Guguan from REA surveys for fishes of all sizes and species was among the highest levels recorded in the Mariana Archipelago. No clear temporal changes were observed for total fish biomass between the 3 MARAMP survey years (Fig. 11.8.1d). Guguan had the greatest estimated species richness of reef fishes recorded in the Mariana Archipelago.

11.11 Summary

MARAMP integrated ecosystem observations include a broad range of information: bathymetry and geomorphology, oceanography and water quality, and biological observations of corals, algae, fishes, and benthic macroinvertebrates along the forereef habitats around Guguan. Methodologies and their limitations are discussed in detail in Chapter 2: “Methods and Operational Background,” and specific limitations of the data or analyses presented in this Guguan chapter are included in the appropriate discipline sections. Methods information and technique constraints should be considered when evaluating the usefulness and validity of the data and analyses in this chapter. The conditions of the fish and benthic communities and the overall ecosystem around Guguan, relative to all the other islands in the Mariana Archipelago, are discussed in Chapter 3: “Archipelagic Comparisons.”

This section presents an overview of the status of coral reef ecosystems around the island of Guguan as well as some of the key natural processes and anthropogenic activities influencing these ecosystems:

- Positioned in the middle of the Mariana Arc, Guguan is the third-smallest island in the Mariana Archipelago with a land area of only 4 km^2.
- Guguan is formed from 2 volcanoes, with the younger of them found in the north. Compared to its neighbor islands, Alamagan and Sarigan, Guguan has a relatively low elevation and less steep slopes.
- Since Guguan likely has not been inhabited and remains relatively undisturbed, it is unique among islands in the Mariana Archipelago in that it supports a diverse range of habitats with a variety of wildlife species. Since 1978, the CNMI Constitution has prohibited inhabitation of Guguan as part of a protected reserve.
- Northern Guguan is surrounded by fairly uniform, smooth flanks, apart from the shallowest depths (< 300 m) where narrow ridges are present. Towed-diver surveys recorded spur-and-of groove habitats of medium to high complexity with predominantly hard substrate and low sand cover.
- South of Guguan, the seabed is characterized by irregularly shaped shelves. A, flat, shallow shelf of hard substrate is located at depths of 25–50 m, and a deeper shelf of soft substrate is located at depths of 80–130 m.
- Overall, the topography of the seafloor around Guguan, characterized by steep slopes to the north and west and an extensive shelf to the south, appears to be very similar to the seascape surrounding the neighbor island of Sarigan.
- Wave model output shows ambient trade wind swells impacting the northeast and southeast regions. Episodic wave energy from storm tracks impact the southwest and southeast regions and to a lesser extent the northwest region.
- Temperature data from STRs deployed at depth of 6 m at a single mooring site on the west side of the island show frequent intraseasonal fluctuations. Recorded temperatures, for example, dropped nearly 3°C in July 2004 for ~ 1 week before sharply increasing to typical summer temperatures. Additionally, temperature values exceeded the coral bleaching threshold in September 2006; however, the duration of this event was < 1 d.

- The overall sample mean for live coral cover was 15.4% from the 3 REA sites surveyed at Guguan in 2007. From towed-diver surveys, islandwide mean cover of live hard corals was 23% in 2003 and 27% in 2007. The overall mean was 10% in 2005, when only 2 towed-diver surveys along the west coast were completed at this island.

- In 2007, 3 REA sites at Guguan were surveyed for the occurrence of disease and predation, and 8 disease cases were detected, all of them at REA site GUG-03 in the northwest region. The overall mean prevalence of disease sites was 0.04% (SE 0.02). Only one disease condition was recorded: an infestation by species of the encrusting sponge Terpios.

- Islandwide mean macroalgal cover, based on towed-diver surveys, was 20% in 2007. Between MARAMP survey years, no towed-diver-survey area consistently had the highest or lowest macroalgal cover.

- Cover of crustose coralline red algae was similar for the 3 MARAMP years, with the highest level observed in the northwest region. Coralline lethal orange disease was the only algal syndrome encountered at Guguan, and only a single case was recorded in the northwest region.

- Overall mean biomass of large fishes during the 3 MARAMP survey years was moderately low relative to estimates made for other northern islands in the Mariana Archipelago but higher than values found at all of the southern islands. However, results from REA surveys for fishes of all sizes and species show that total fish biomass at Guguan, with an overall sample mean of 18.20 kg 100 m^{-2} (SE 0.86) across the 3 survey periods, was among the highest levels found in the Mariana Archipelago.

- Notable observations of large fishes included a sighting of a humphead wrasse (Cheilinus undulatus) in 2007 and sightings of giant trevally (Caranx ignobilis) in 2005 and 2007.

- No COTS were observed in 2007; however, low densities were recorded in 2003 and 2005.

- Overall observed densities of sea cucumbers were low around Guguan during the 3 MARAMP survey years. Comparatively, giant clams were common, especially on the west side, where they were abundant. Sea urchins mostly were observed on the east side. Islandwide observed densities of sea urchins were higher in 2007 than in 2003.

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